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Stratigraphy, sedimentology, and provenance of the lower Campanian Forbes and Marsh Creek formations, southern Sacramento and northern San Joaquin Basins, California

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STRATIGRAPHY, SEDIMENTOLOGY, AND PROVENANCE OF THE LOWER CAMPANIAN FORBES AND MARSH CREEK FORMATIONS, SOUTHERN SACRAMENTO AND NORTHERN SAN JOAQUIN BASINS, CALIFORNIA

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ABSTRACT

The lower Campanian Forbes and Marsh Creek formations represent submarine-fan/slope systems that were deposited in the northern Great Valley forearc basin. These coeval units are bounded by two shale units, the Dobbins Shale below and the Sacramento Shale above, shown by correlation of their unique faunas to be basinwide in extent. These two lower Campanian fan systems are distinguished on the basis of data from well logs, surface sections, paleocurrent orientations, and sandstone composition.

The Forbes Formation represents a mud-rich-fan system characterized by meandering channel-levee complexes that prograded southward down the plunging axis of the forearc basin. The Marsh Creek Formation represents a mixed-sediment system comprised of outer-fan lobes, middle-fan channels, and inner-fan channels. This unit prograded to the west and southwest, transverse to the basin axis. Initially the Marsh Creek system was confined to the structurally controlled Stockton subbasin, but later it spread out across the basin floor.

The data show distinct differences between the two systems suggesting that there was no mixing of the sediment delivered to them. Surface and subsurface mapping also suggests that the two systems did not overlap. This study shows that two separate submarine-fan systems, with

contrasting depositional facies, transport directions, source areas, and structural controls, can form coevally within the same forearc basin setting.

INTRODUCTION

The lower Campanian Forbes and Marsh Creek formations represent submarine-fan systems that crop out along the western margin of the Sacramento basin of California. These systems are part of the Great Valley Group, a thick section of deep-marine siliciclastic deposits that filled the Late Mesozoic Great Valley forearc basin (Ingersoll, 1982, 1990). The Forbes Formation has been recognized in outcrop as far north as Black Butte Reservoir and south to the Coast Ranges north of Vacaville (fig. 1). This unit is best exposed in the Rumsey Hills area, where it originally was mapped and named by Kirby (1943). The Forbes Formation is widely recognized by subsurface workers; it has been penetrated by more than 2,000 wells and has produced large amounts of gas (California Division of Oil and Gas, 1986). The Marsh Creek Formation is exposed in the northeastern Diablo Range (fig. 1), where it was named informally by Cherven and Bodden (1983). This unit is poorly understood in the subsurface and has produced only minor amounts of gas.

Problem and Objectives

Previous work on Upper Cretaceous rocks in the southern Sacramento and northern San Joaquin basins has led to the assignment of different stratigraphic names to time-

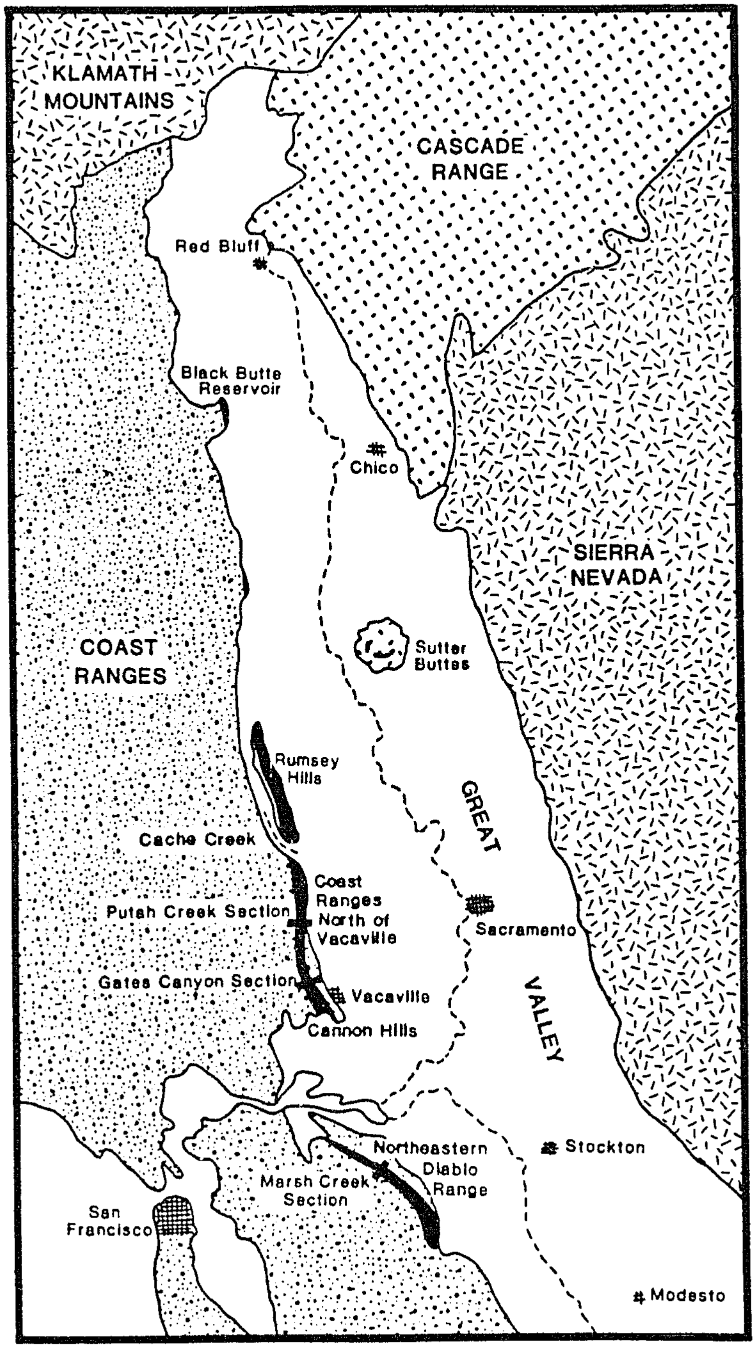


Figure 1. Index map of the Sacramento and northern San Joaquin valleys and adjacent geologic terranes showing locations of major cities, measured outcrop sections, and outcrops of lower Campanian strata (in black).

equivalent strata in the Coast Ranges north of Vacaville and the northeastern Diablo Range. Lower Campanian strata were mapped by Emerson and Roberts (1962) as the Forbes Formation in the Coast Ranges north of Vacaville and informally named the Marsh Creek Formation or "Marsh Creek Fan" in the northeastern Diablo Range by Cherven and Bodden (1983). These units have been assigned different names because of the geographic separation of the outcrop localities and their uncertain subsurface distribution. No investigation of the possible relationship between these two units has been undertaken previously.

Subsurface mapping of the Forbes Formation in the northern and central Sacramento basin indicates that it is a mud-rich submarine-fan/slope system that prograded southward down the plunging axis of the Sacramento basin (Imperato and others, 1990). In the southern Sacramento and northern San Joaquin basins, very few wells penetrate into these rocks because of their great depth. This lack of subsurface control has hindered understanding of the stratigraphic relationship between the Marsh Creek Formation and the Forbes Formation.

Scope of Study

A detailed study focusing on stratigraphy, sedimentology, provenance, biostratigraphy, and subsurface data is necessary to resolve the inconsistencies in previous mapping of the Forbes strata in the Coast Ranges north of Vacaville, in its temporal equivalents in the northeastern Diablo Range, and in the subsurface. A better understanding of the relationship between the Forbes and Marsh Creek Formations is developed through research in six principal areas:

(1) Verification of biostratigraphic correlations by integration of data from new samples, from previously confidential reports, and from published literature.

(2) Detailed measurement of three stratigraphic sections (Putah Creek and Gates Canyon in the Coast Ranges north of Vacaville and Marsh Creek in the northeastern Diablo Range).

(3) Geologic mapping of the Forbes Formation and equivalent strata in the vicinity of the three measured sections.

(4) Measurement of paleocurrent indicators in the vicinity of the stratigraphic sections.

(5) Correlation of more than 200 well logs to determine subsurface relationships through the construction of subsurface maps (plates 1-4) and regional stratigraphic cross sections (plates 5-9), based on information from a subsurface log-correlation database.

(6) Provenance studies based on 27 sandstone samples

from the three detailed stratigraphic measured sections and the Cannon Hills (fig. 1).

Geography and Access

The study area includes the central portion of the Great Valley extending from the Sierran foothills on the east to the Coast Ranges on the west. The limits of the area examined extend from the northern edge of T.12N., about 25 mi (55 km) north of Sacramento, to the southern edge of T.5S., about 13 mi (27 km) south of Modesto (fig. 1). The western and eastern limits of the study area follow the configuration of the valley, extending from R.3W. to R.11E.

The Great Valley is a generally flat, low-lying area covered primarily by the alluvial, fluvial, and delta plains of the Sacramento and San Joaquin rivers. Along the western margin of the valley, the Coast Ranges rise more than 2800 ft (850 m) above the valley floor. The eastern Coast Ranges are underlain by north-south-trending and east-dipping Cretaceous and Tertiary sedimentary rocks. Topography in this area is very rugged, with numerous north-south-trending ridges underlain by resistant sandstone and conglomerate beds. East-directed drainages cut through the north-south-trending strata to form canyons that provide good exposures of the sedimentary sequence.

REGIONAL FRAMEWORK

The Cretaceous paleogeography along the California continental margin is dominated by the Great Valley forearc basin (Ingersoll, 1979, 1982). The setting of the forearc basin is comprised of three main components (fig. 2): (1) the Sierra Nevada magmatic arc to the east, (2) the Great Valley forearc basin itself, and (3) the Franciscan subduction complex to the west (Dickinson, 1970; Dickinson and Seely, 1979). A fourth component farther north is the composite Klamath terrane, which may have created a westward bulge in the coastline north of the forearc basin (Ingersoll and Schweickert, 1986).

Plate reconstructions support the existence of a convergent margin along the western margin of North America during the Cretaceous (Engebretson and others, 1985; Debiche and others, 1987). Reconstructions indicated that the oceanic Farallon plate was moving in a northeastward direction and being subducted beneath the relatively stable continental North American plate during the Cretaceous. The interaction between these two plates formed the Great Valley forearc basin. Paleogeographic reconstructions of western North America for the Campanian by Nilsen (1986) showed the Great Valley forearc basin as one of several forearc basins formed by the subduction of the Farallon and

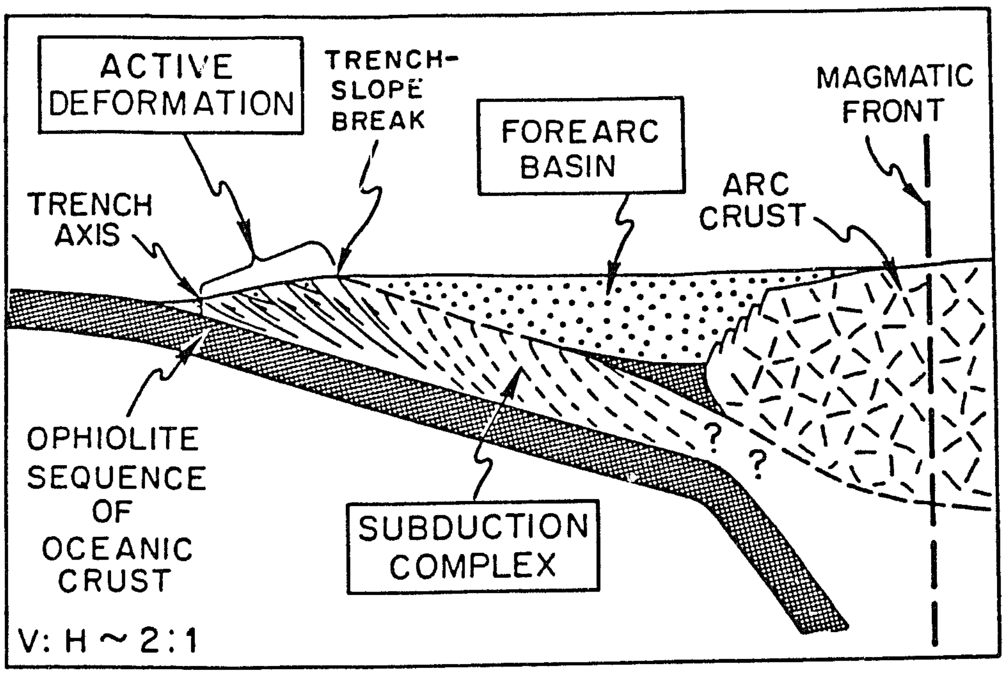


Figure 2. Illustration of the three main components of the late Mesozoic forearc basin (modified from Ingersoll and Dickinson, 1981).

Kula plates. This continental margin, where eastward-subducting oceanic lithosphere formed a trench and outer-arc ridge along a continental margin, is classified as Andean by Dickinson (1981). A volcanic arc formed on the continental block to the east as a result of the subducting oceanic lithosphere; the forearc basin was situated between the trench and arc.

The Great Valley forearc basin formed subsequent to the collision of an intraoceanic arc with continental North America during the Nevada orogeny (Schweickert and Cowan, 1975; Burchfield and Davis, 1981; Saleeby, 1981; Ingersoll, 1983; Schweickert and others, 1984). A new east-dipping subduction complex formed to the west of the suture, creating the Franciscan-Great Valley-Sierra Nevada system (fig. 3). This system persisted along the western margin of North America until the inception of the San Andreas transform boundary in the Miocene.

Sierra Nevada

The Sierra Nevada is in part a Mesozoic batholithic complex that was intruded into Paleozoic and Mesozoic strata. The country rocks have a wide range of lithologic types and are strongly deformed but typically weakly metamorphosed (Bateman, 1983). The western metamorphic belt is composed mostly of upper Paleozoic and lower Mesozoic rocks regionally metamorphosed to greenschist

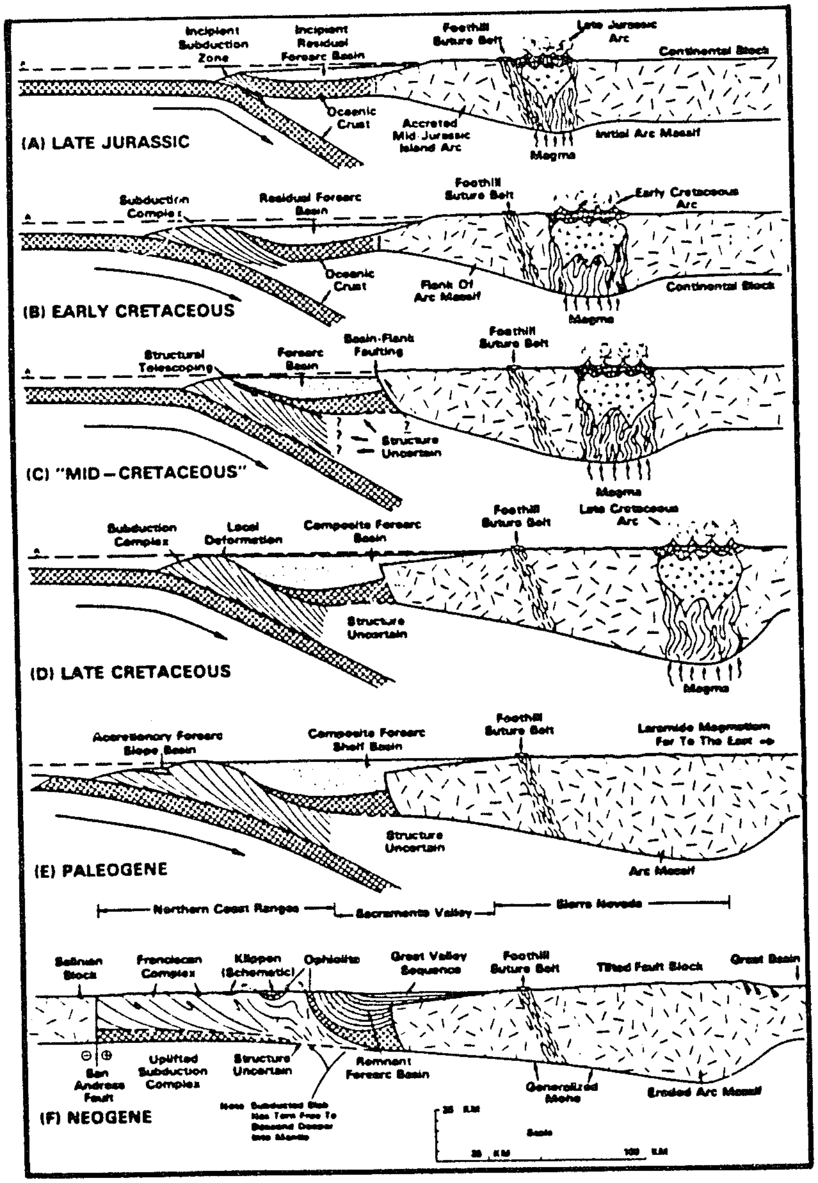


Figure 3. Schematic cross sections of northern California showing the Late Jurassic to Neogene evolution of the Great Valley forearc basin (modified from Dickinson and Seely, 1979).

facies. These rocks represent ophiolitic sequences, metavolcanic rocks, and sedimentary strata thought to have been deposited along oceanic ridges and island arcs that were subsequently accreted to the continental margin. The Precambrian and Paleozoic strata in the Inyo and White mountains to the east and the roof pendants in the eastern Sierra Nevada consist primarily of quartzite, carbonate, and pelitic rocks deposited in a miogeoclinal setting. The roof pendants and septa within the batholith have undergone thermal metamorphism to the albite-epidote hornfels facies (Bateman, 1983).

The batholiths emplaced during the Mesozoic are in sharp contact with each other or with the country rock (Bateman, 1983). The western Sierra Nevada is characterized by tonalite and quartz diorite; granodiorite is most common in the central part of the range; and quartz monzonite and monzonite are typical of the granitoids to the east. This reflects an eastward increase in potassium, which is independent of the age of the granitoids.

The U-Pb ages of the plutons reflect two distinct periods of magmatism; one was active the Triassic to Jurassic between 206 Ma and 155 Ma, and the other was during the Cretaceous from 125 Ma to 88 Ma (Bateman, 1983). During the Nevadan orogeny between 155 Ma and 125 Ma, plutonism was inactive. The distribution of plutons shows Cretaceous granitoids flanked by Jurassic intrusions with

Triassic plutons to the east. This suggests that the Jurassic plutons were fairly widespread and were subsequently partially destroyed by intrusion of the Cretaceous granitoids (Bateman, 1983).

Models showing the tectonic evolution of the Sierra Nevada have been erected by various workers (Schweickert and Cowan, 1975; Schweickert, 1981; Saleeby, 1981). Although these models have some differences, they all generally fit into the arc-trench model for the Great Valley forearc basin developed by Ingersoll (1982).

Klamath Mountains

The Klamath Mountains geologic province is a west-facing arcuate structure consisting of several tectonostratigraphic terranes with different types and sequences of sedimentary rocks of different ages and different plutonic rocks (Irwin, 1981, 1985). The Klamath Mountains extend from northwestern California into southwest Oregon and form the northern boundary of the Great Valley. The terranes are composed of oceanic crust and island arcs ranging in age from early Paleozoic to Jurassic. Detailed study of plutonic and ophiolitic belts within the Klamath Mountains has helped clarify the age relationships of the terranes (Saleeby and others, 1982; Irwin, 1985). The terranes are thought to have been amalgamated on oceanic lithosphere prior to their accretion to North America prior to Early Cretaceous time (Irwin, 1985).

The composite Klamath terrane can be divided into four principal terranes, (1) the Eastern Klamath terrane, (2) the Central Metamorphic terrane, (3) the composite Western Paleozoic and Triassic terrane, and (4) the Western Jurassic terrane. These terranes are considered to represent an amalgamated sequence of eastward-dipping imbricate thrust plates (Irwin, 1981). The Eastern Klamath terrane forms the nucleus of the province; it represents an early Paleozoic to Jurassic volcanic arc built on oceanic crust. The Central Metamorphic terrane represents part of a subduction complex that formed during eastward subduction beneath the Eastern Klamath terrane in the Devonian. The Western Paleozoic and Triassic composite terrane, which includes the Rattlesnake Creek, Hayfork, and North Fork terranes and the Western Jurassic terrane, consists mostly of oceanic material that was accreted to the Paleozoic nucleus during the Jurassic (Irwin, 1985).

The Klamath terrane has been intruded by a series of plutons ranging up to Early Cretaceous in age (Irwin, 1985). Paleogeographic models developed by Irwin (1984, 1985) suggest that the Klamath terranes were amalgamated and rotated clockwise west of the North American continent from the Devonian to Jurassic. This was followed by accretion of the composite Klamath terrane to the continental margin in latest Jurassic or earliest Cretaceous time. It is evident that the terrane was accreted by the Cretaceous, because it was a source for Lower Cretaceous strata of the Great Valley Group (Short and Ingersoll, 1990).

Franciscan Assemblage

The Franciscan Assemblage, highly complex rocks with varying stratigraphy, age, metamorphic grade, and structural state, make up a large portion of the Coast Ranges of northern and central California (Blake and others, 1985). This assemblage, which is thought to be an accretionary complex that formed largely in and above a subduction zone west of the Great Valley forearc basin, is made up of several tectonostratigraphic terranes that have undergone a complex history of subduction, accretion, and translation. Subduction and accretion of the terranes began in the latest Jurassic after the Nevadan orogeny and continued until the initiation of the San Andreas fault system in the Miocene.

The Franciscan rocks can be divided into three fault-bounded belts, the Eastern, Central, and Coastal belts, which can be further subdivided into tectonstratigraphic terranes (McLaughlin and others, 1982; Blake and others, 1984, 1985). The metamorphic mineral assemblages show a progressive increase in grade eastward.

The Eastern belt can be subdivided into the Pickett Peak and Yolla Bolly terranes. The Pickett Peak terrane, which is composed of quartz-veined mica schist, metagraywacke, metavolcanics, and metachert has been interpreted as representing oceanic crustal and supracrustal rocks. The Yolla Bolly terrane is composed of metagraywacke, argillite, and radiolarian chert, deposited in a continental margin basin setting, and alkalic gabbro sills and dikes. These two terranes have metamorphic radiometric ages between 90 and 143 Ma and are metamorphosed to the blueschist facies, suggesting conditions of subduction (Jayko and others, 1986).

The Central belt is primarily a tectonic melange with a sheared matrix of argillite, lithic graywacke, and greenish-gray radiolarian tuff. Within this melange are resistant blocks or "knockers" of greenstone, chert, limestone, graywacke, ultramafic rocks, and high-grade metamorphic rocks (Blake and others, 1985). It is thought that this melange formed within an accretionary wedge at the interface between an oceanic plate and the North American continental margin. Fossils show that these rocks range in age from Late Jurassic to Early Cretaceous. Paleontologic and paleomagnetic data from limestones suggest deposition in equatorial latitudes during the Early

Cretaceous, suggesting rapid transport on oceanic plates (Alvarez and others, 1980; Tarduno and others, 1986).

The Coastal belt can be subdivided into the Coastal, Yager, and King Range terranes (Blake and others, 1985). These units are dominated by sheared and fractured mudstone, sandstone, conglomerate, basalt, and chert. These terranes range in age from Paleocene to middle Eocene and have been interpreted as trench-slope deposits (Blake and others, 1985).

The contact between the Franciscan Assemblage and the Great Valley Group originally was thought to be a thrust fault, the Coast Range thrust (Brown, 1968; Bailey and Blake, 1969); however, more recent studies suggest that this contact may be a high-angle normal fault (Jayko and others, 1987). The Coast Range ophiolite, the oceanic crust that forms the base of the the Great Valley Group, is exposed in many places along this contact (Bailey and others, 1970; Hopson and others, 1981). The Franciscan rocks in the northeastern Diablo Range represent a piercement intrusion, primarily serpentinite, that has uplifted the Great Valley Group (Pampeyan, 1961, 1964).

Great Valley Group

The Great Valley Group (Ingersoll and Dickinson, 1981; Ingersoll, 1990) includes the upper Mesozoic and Danian strata along the western margin of the Sacramento Valley, correlative strata along the western margin of the San Joaquin Valley, and equivalent strata in the subsurface. This group of rocks was formerly called the Great Valley sequence (Bailey and others, 1964). The Great Valley Group is composed chiefly of siliciclastic, deep-marine turbidites that were deposited in the Great Valley forearc basin (Ingersoll, 1978). The present structure of the Great Valley is that of an asymmetrical syncline that has a general north-south trend (Ingersoll and Dickinson, 1981). The western limb is characterized by extensive outcrops of deep-marine strata that dip steeply to the east. The eastern limb is represented by limited exposures of gently west-dipping, shallow-marine strata that rest upon Sierran basement.

The strata along the western margin of the Sacramento Valley first were subdivided by Kirby (1943) into the Venado, Yolo, Sites, Funks, Guinda, and Forbes formations. Goudkoff (1945) subdivided the Great Valley Group into time-stratigraphic units using benthic foraminifera; this classification was later modified and expanded upon by Berry (1974) and Almgren (1986).

Petrographic studies of the Great Valley Group have shown that the Sierra Nevada batholith and Klamath Mountains were the principal sources of sediment for the Great Valley forearc basin (Ingersoll, 1983). Mertz (1990) has also suggested the Idaho batholith as a source for part of the Great Valley Group. The initial studies along the western margin of the Sacramento basin (Dickinson and Rich, 1972) and the western margin of the San Joaquin basin (Mansfield, 1979) led to the division of the Great Valley Group into five petrographic units. Ingersoll (1983) expanded upon the previous work and divided the Great Valley Group into six units he called petrofacies. The petrofacies record the unroofing of the Sierran batholiths; older units have higher proportions of surficial volcanic detritus, whereas the younger units have increased amounts plutonic material, particularly potassium feldspar, from deep-seated sources.

Submarine-fan facies and related deposits including basin plain, outer-fan, midfan, inner-fan, and slope deposits have been recognized in the Great Valley Group (Ingersoll, 1978). Progradational and retrogradational suites were recognized based on the arrangement of these facies (Ingersoll, 1978). Sedimentologic studies along the western margin of the basin have suggested deposition by south-flowing turbidity currents (Ojakangas, 1968), but other studies have suggested predominantly west-directed paleocurrents (Ingersoll, 1978).

Because of the large volumes of hydrocarbons produced from strata of the Great Valley Group, many subsurface studies have been conducted. Regional subsurface studies have shown that Cretaceous slope, shelf, and deltaic deposits, in addition to the submarine-fan deposits, are present beneath the Sacramento Valley (Garcia, 1980; Cherven, 1981; Nilsen, 1990). More detailed studies have demonstrated the stratigraphic relationships between submarine-fan/slope/delta systems and the importance of basinwide shale deposits for correlation purposes (Drummond and others, 1976; Imperato and others, 1990; Moore and Nilsen, 1990).

PREVIOUS WORK

Stratigraphic Framework

The strata cropping out around the margins of the Great Valley have been the subject of numerous studies since the mid-1800s. Studies focusing on mapping, stratigraphy, sedimentology, petrography, biostratigraphy, and the subsurface have led to a wide range of stratigraphic nomenclatural schemes. The most significant problem, which is made evident by this study, is the assignment of different stratigraphic names to time-equivalent strata at different localities. The stratigraphic nomenclature of the rocks bordering the Great Valley was initially developed through mapping efforts in the second half of the 1800s and the early 1900s. These strata were divided into the "Knoxville" (Upper Jurassic), "Shasta" (Lower Cretaceous), "Chico" (Upper Cretaceous), and "Martinez" (Paleocene). This early work around the margins of the Great Valley was summarized by Matsumoto (1959) and Popenoe and others (1960). Nilsen (1990) reviewed the evolution of the stratigraphic framework of the Santonian, Campanian, and Maestrichtian strata in the Sacramento Valley and synthesized data that have led to the present understanding of surface and subsurface units.

The biostratigraphic framework was established by

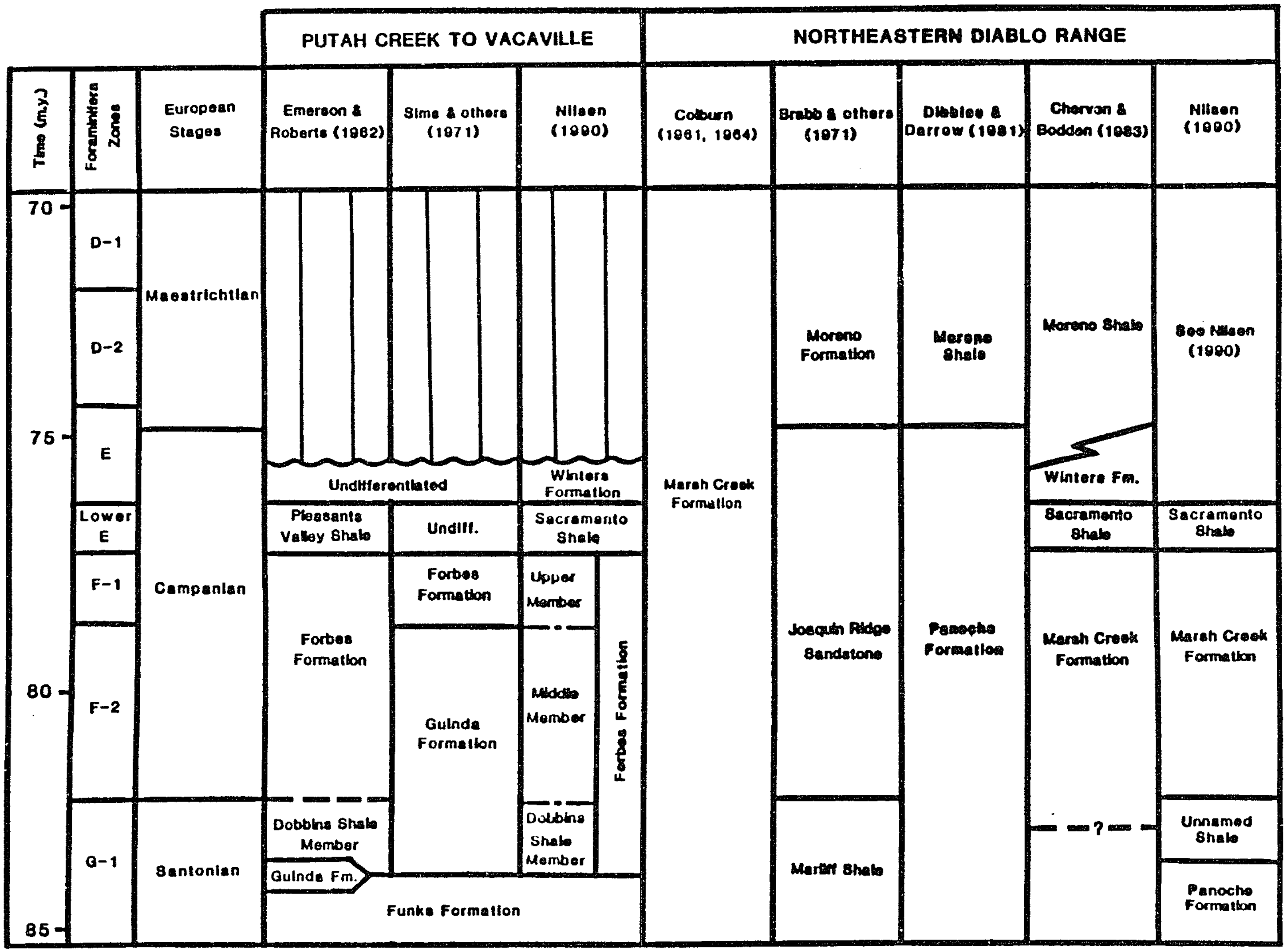
Goudkoff (1945), who used benthic foraminifera to define a zonation for the Upper Cretaceous strata of the Sacramento and San Joaquin valleys. He erected eleven zones labelled C through J-1. The zones significant to this study are shown on Figure 4.

Almgren (1986) showed that the Forbes Formation in the Putah Creek and Cannon Hills area corresponds to the F-1 and F-2 zones. Almgren showed that F-zone strata extend southward into the northeastern Diablo Range where he referred to them as "Forbes" sandstones. The F-zone strata are underlain by G-1-zone strata, represented by the Dobbins Shale Member of the Forbes Formation in the Coast Ranges north of Vacaville and an unnamed shale in the northeastern Diablo Range. Overlying the F zone is the Lower E zone, which contains a very distinctive microfossil assemblage. This zone is represented in the Sacramento Shale in the Coast Ranges north of Vacaville and the "white radiolarian shale" of Colburn (1964) in the northeastern Diablo Range (Almgren, 1986).

Coast Ranges North of Vacaville

The Upper Cretaceous "Chico series" was first divided by Kirby (1943) into, in ascending stratigraphic order, the Venado, Yolo, Sites, Funks, Guinda, and Forbes formations. Kirby's mapping extended from north of the Rumsey Hills, south to the Putah Creek area, although he did not map all

Figure 4. Late Cretaceous European stages and associated time divisions (modified from Palmer, 1983), benthic foraminiferal zones (modified from Goudkoff, 1945), and most recent stratigraphic nomenclature for the Coast Ranges north of Vacaville (Putah Creek to Vacaville) and the northeastern Diablo Range.


PUTAH CREEK TO VACAVILLE
NORTHEASTERN DIABLO RANGE
Time (m.y.)
Foraminifera Zones
European Stages
Emerson & Roberts (1982)
Sims & others (1971)
Nilsen (1990)
Colburn (1961, 1964)
Brabb & others (1971)
Dibblee & Darrow (1981)
Chervan & Boddan (1983)
Nilsen (1990)
70
75
80
85
D-1
D-2
E
Lower E
F-1
F-2
G-1
Maestrichtian
Campanian
Santonian
Undifferentiated
Winters Formation
Pleasants Valley Shale
Undiff.
Sacramento Shale
Forbes Formation
Upper Member
Middle Member
Guinda Formation
Forbes Formation
Dobbins Shale Member
Guinda Fm.
Funks Formation
Marsh Creek Formation
Moreno Formation
Joaquin Ridge Sandstone
Marlliff Shale
Moreno Shale
Panoche Formation
Winters Fm.
?
See Nilsen (1990)
Unnamed Shale

of these units continuously from the south flank of Cache Creek to Putah Creek (fig. 1).

Correlation and nomenclatural problems developed when work was focused on local areas. The primary source of problems stemmed from correlation of the Guinda and Forbes formations. Workers in the Rumsey Hills area who followed Kirby (1943) included Goudkoff (1945), Jennings (1954), Brooks (1962a,b), Court (1966), and Wagner and Saucedo (1984). Along the south flank of Cache Creek, Jennings (1954) mapped the Guinda Formation as unconformably underlying the Pliocene Tehama Formation, but Brooks (1962a,b), Sonneman and Switzer (1962), and Sims and others (1971) mapped these rocks as the Forbes Formation.

In the Putah Creek area the mapping of Kirby (1943) and Goudkoff (1945) does not correspond. Along Putah Creek, Kirby (1943) subdivided the Forbes into the Dobbins Shale, middle, and upper members. Goudkoff (1945) mapped the Dobbins Shale Member and middle member of Kirby's Forbes Formation as the Guinda Formation. Subsequent mapping by Emerson and Roberts (1962) is consistent with Kirby (1943); they also mapped a thin shale, the Pleasants Valley Shale, above the Forbes Formation (fig. 4). Sonneman and Switzer (1962) divided the Forbes into a lower member and an upper claystone member and mapped a thin shale above the Forbes, the Sacramento Shale, which corresponds with the Pleasants Valley Shale of Emerson and

Roberts (1962). Mapping by Sims and others (1971) was similar to that of Goudkoff (1945) in this area; however, Sims and others (1971) have also included an undifferentiated shale unit at the top of the Forbes. Emerson and Roberts (1962), Sonneman and Switzer (1962), and Sims and others (1971) extended their mapping southward to the Vacaville area (fig. 4). The mapping by these workers here is consistent with their work in the Putah Creek area; however, Emerson and Roberts (1962) showed the Guinda Formation pinching out southward.

The correlation problems in the Coast Ranges from the Rumsey Hills south to Vacaville have been partly resolved as the result of biostratigraphic studies. Almgren (1986) demonstrated that Forbes Formation of Kirby (1943) and Emerson and Roberts (1962) generally correlates with the F zone. The Dobbins Shale Member corresponds to the uppermost G-1 zone and the Forbes Formation correlates with the F-1 and F-2 zones. Studies of ammonites and magnetostratigraphy (Haggart and Ward, 1984), planktic foraminifers (Trosper, 1985), radiolaria (Pessagno, 1976) and calcareous nannofossils (Filewicz, 1986) have also helped to confirm these relationships.

Northeastern Diablo Range

The stratigraphic nomenclature of the Upper Cretaceous rocks in the northeastern Diablo Range has undergone a confusing evolution. Units have been assigned names extended northward from the central and southern Diablo Range, southward from the Coast Ranges, and from the subsurface, in addition to names applied only locally.

Taff (1935) was the first to divide the Upper Cretaceous in the northeastern Diablo Range. He mapped, in ascending stratigraphic order, the Shasta, Chico, Panoche, and Moreno Formations. Colburn (1961, 1964), working primarily in the northeastern Diablo Range (fig. 4), divided this sequence into the Marsh Creek Formation (J to D-1 zone) and the Deer Valley Formation (C zone). Sonneman and Switzer (1962) extended units northward from the central and southern Diablo Range based on previous mapping by Huey (1948), Oestreich (1958), and Payne (1960). Their Joaquin Ridge Sandstone included the uppermost G-1, F-2, F-1, and part of the E zone. Brabb and others (1971) also extended units from the central Diablo Range. They divided the Cretaceous sequence, in ascending stratigraphic order (fig. 4), into an unnamed sandstone and shale, Marliff Shale of Payne (1960), Joaquin Ridge Sandstone of Goudkoff (1945), Moreno Formation of Payne (1960), and Deer Valley Formation of Colburn (1964).

Dibblee (1980a,b,c,d) and Dibble and Darrow (1981) attempted to simplify the nomenclature by dividing the Upper Cretaceous rocks into the Panoche Formation and

Moreno Shale (fig. 4). The boundary between these units was based on a significant decrease in sandstone in the upper part of the section. Cherven and Bodden (1983) modified the geologic mapping of Brabb and others (1971) along Marsh Creek and Deer Valley roads (fig. 4). They recognized the Sacramento Shale, based on its distinctive microfossil assemblage, and the overlying E-zone Winters Formation, units that originally were recognized in the subsurface. Beneath the Sacramento Shale they showed a Marsh Creek Formation or "Marsh Creek Fan" composed of lower-fan, middle-fan, middle-fan-interchannel, and channel facies. This unit includes F-2 and F-1 zone strata; however, Cherven and Bodden (1983) did not specify the location of the base of the unit. Almgren (1986) elected to extend the Sacramento Valley units southward to the northeastern Diablo Range, where he used "Forbes" sandstone to describe the F-zone strata.

Subsurface Stratigraphy

The discovery of significant hydrocarbon accumulations in Upper Cretaceous strata in the Sacramento basin during the 1950s led to a number of subsurface studies (Chuber, 1962; Reid, 1962; Safonov, 1962, 1968; Weagant, 1962, 1972; Edmonson, 1962, 1967). Edmondson (1962) was the first to study the Forbes Formation in the subsurface in some detail. He recognized the lateral equivalence of the shallow marine Kione and deep marine Forbes formations. He noticed that the F-zone Forbes Formation thinned eastward, and he placed an unconformity between it and the underlying G-zone Dobbins Shale. Edmondson (1962) suggested that the Forbes Formation was derived from westward-flowing rivers draining the Sierra Nevada. Thomson (1962) studied the Kione Formation and concluded that it had prograded southward from the north and east.

Detailed studies of the Forbes Formation led to a great deal of confusion regarding the depositional environment, facies, and geometry of the productive sandstone bodies. Graham (1981) recognized the turbiditic nature of this unit and believed that the Forbes represented middle-fan deposits in the subsurface and basin-plain deposits in the outcrop. Tillman (1985) suggested that sandstones in gas field areas in the central portion of the basin were laterally continuous outer-fan lobe deposits. Ward (1985) thought that the Forbes Formation is composed of thick channel sandstones interbedded with thin shales overlain by a thick shale interval. Moser and others (1986) determined that the Forbes Formation consists of both outer- and middle-fan deposits overlain by slope and shelf deposits.

Fischer and others (1986) studied cores of the Forbes Formation and observed cyclic sequences of thin-bedded mudstone, siltstone, and sandstone with Bouma sequences.

Rider (1986) suggested that the Dobbins Shale Member of the Forbes Formation was deposited near the shelf-slope break and was locally scoured during formation of submarine canyons that were subsequently filled and overlain by the Forbes Formation. Morgan and Champion (1987) suggested that the Forbes and Kione depositional system was deposited during a eustatic sea-level fall.

The most recent work on the Forbes Formation suggests that it is a mud-rich, basin-plain, deep-sea-fan, and slope turbidite system that prograded southward down the Cretaceous forearc basin (Imperato and others, 1990). The source of sediment for this system is thought to be north of the present basin margin (Mertz, 1990). The Forbes Formation is divided into the Dobbins Shale Member, an unnamed middle member, and an unnamed upper member. The Forbes is overlain in the northern and central Sacramento basin by the fluvial-dominated deltaic deposits of the Kione Formation (Garcia, 1981; Imperato and others, 1990).

The Dobbins Shale Member represents basin-plain deposits that blanketed the basin during a relative sea-level high-stand (Imperato and others, 1990); it is characterized by a low-resistivity log response and corresponds to the G-1 zone (Imperato and others, 1990). The unnamed middle member consists of vertically stacked channel-levee complexes containing, channel, channel-margin, levee, and interchannel facies corresponding to the F-2 zone (Imperato and others, 1990). Detailed correlation of low-resistivity shale markers within the Forbes has helped delineate the channelized, discontinuous nature of the productive sandstones (Imperato and Nilsen, 1990). These channel-levee complexes form the reservoirs for the majority of the gas produced from the Forbes Formation (Weagant, 1986; Weagant and Sterling, 1989). The unnamed upper member, which corresponds to the F-1 zone, is dominated by mudstone except where cut by sandstone-filled gully deposits which acted as conduits for transport sediment from the Kione delta to the deep-sea-fan (Imperato and others, 1990).

Submarine-fan Models

An understanding of submarine-fan systems has been developed through the study of both modern and ancient systems. The sedimentary processes involved in the deposition of deep-water clastic systems, primarily turbidity currents, are especially important. Middleton and Hampton (1973, 1976) recognized four types of sediment-gravity flows that transport deep-water clastic sediment: (1) turbidity currents, (2) fluidized sediment flows, (3) grain flows, and (4) debris flows. Sediment deposited by turbidity currents forms the Bouma (1962) sequence. This sequence contains up to five divisions, a and b representing deposition in the upper flow regime, c and d representing the lower flow regime, and e representing pelagic sedimentation (Middleton and Hampton, 1976; Lowe, 1982). The turbidite is the basic element of submarine-fan deposition.

Mutti and Ricchi Lucchi (1972) developed a classification of deep-water clastic deposits based on descriptive characteristics such as thickness, grain size, geometry, structure, and the Bouma sequence. In this classification the letters A to G are used to designate seven turbidite facies. This facies classification has become the foundation for studying deep-water clastic systems worldwide. Mutti and Ricchi Lucchi (1972) have applied these facies to twelve facies associations for their submarine-fan model. Nelson and Nilsen (1984) provided an excellent summary of the facies and facies associations of Mutti and Ricchi Lucchi (1972).

The Mutti and Ricchi Lucchi (1972) classification has gained wide acceptance; however, this scheme was derived from only one type of submarine fan: that with mixed sediment types that originate from a single feeder system. The study of both modern and ancient turbidite systems by many workers throughout the world has developed three models that serve as end members to a broad spectrum of submarine-fan types. These three types of submarine fans are (1) mixed-sediment fans, (2) sand-rich fans, and (3) mud-rich fans (Nelson and Nilsen, 1984).

The Mutti and Ricchi Lucchi (1972) classification applies best to mixed-sediment fans. These are characterized by a mixture of grain sizes and have well developed outer-fan lobe deposits. These are also referred to as efficient fans because of their ability to transport sediment considerable distances (Mutti, 1979).

Normark (1970, 1978) studied modern fans off the coast of southern California and recognized small, mounded deep-sea fans. He named the topographic bulges, the locus of sedimentation, suprafans. This type of fan is referred to as a sand-rich fan. These are generally small, dominated by sand, and have poorly developed outer-fan lobe deposits. A number of sand-rich fans have been identified in the ancient record (Nilsen, 1979, 1981; Link and Nilsen, 1980; Link, 1981; Moore and Nilsen, 1990).

Mud-rich fans are not well documented in the ancient record, but they are well known in our modern oceans (Garrison and others, 1982; Damuth and others, 1983; Bellaiche and others, 1984; Nelson and others, 1985). These fans generally are very large, elongate, dominated by fine-grained sediment, and have poorly developed outer-fan lobes. Typically, the entire length of the fan is composed of meandering channel-levee complexes separated by extensive mud-dominated interchannel areas.

BIOSTRATIGRAPHIC CORRELATIONS

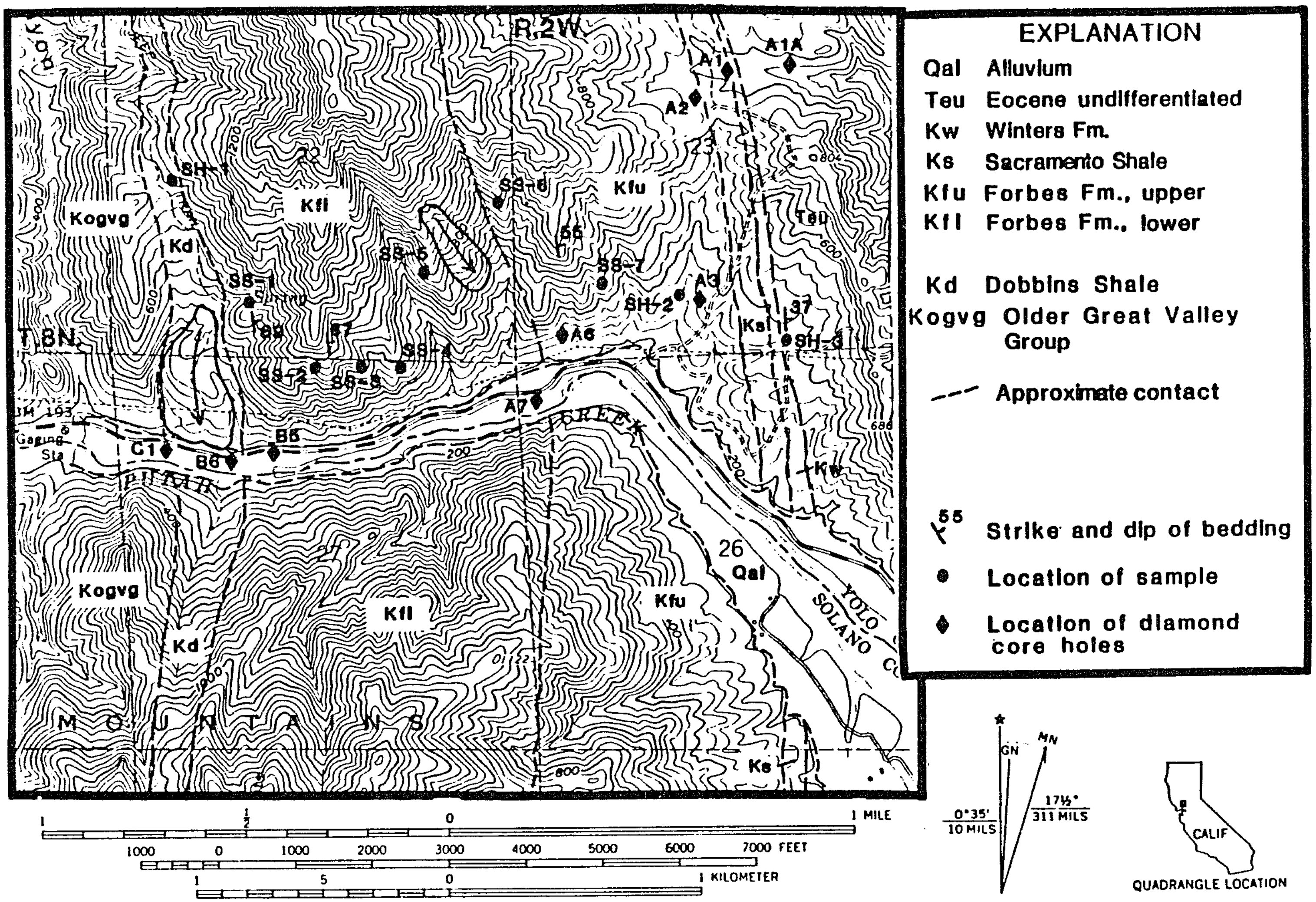
Methods

The goal of the biostratigraphic analysis was to establish time-stratigraphic correlations between the Coast Ranges north of Vacaville and the northeastern Diablo Range. The data used in this analysis are from a combination of published literature, unpublished reports, and newly acquired outcrop samples. The unpublished reports were provided courtesy of Applied Earth Technology, Inc., but the data provided were limited to information concerning the foraminiferal zones of Goudkoff (1945); lists of species were not released. Shale samples were collected by the writer from Putah Creek, Gates Canyon, Cannon Hills, and Marsh Creek (figs. 5-8) to supplement the published literature and unpublished reports.

Coast Ranges North of Vacaville

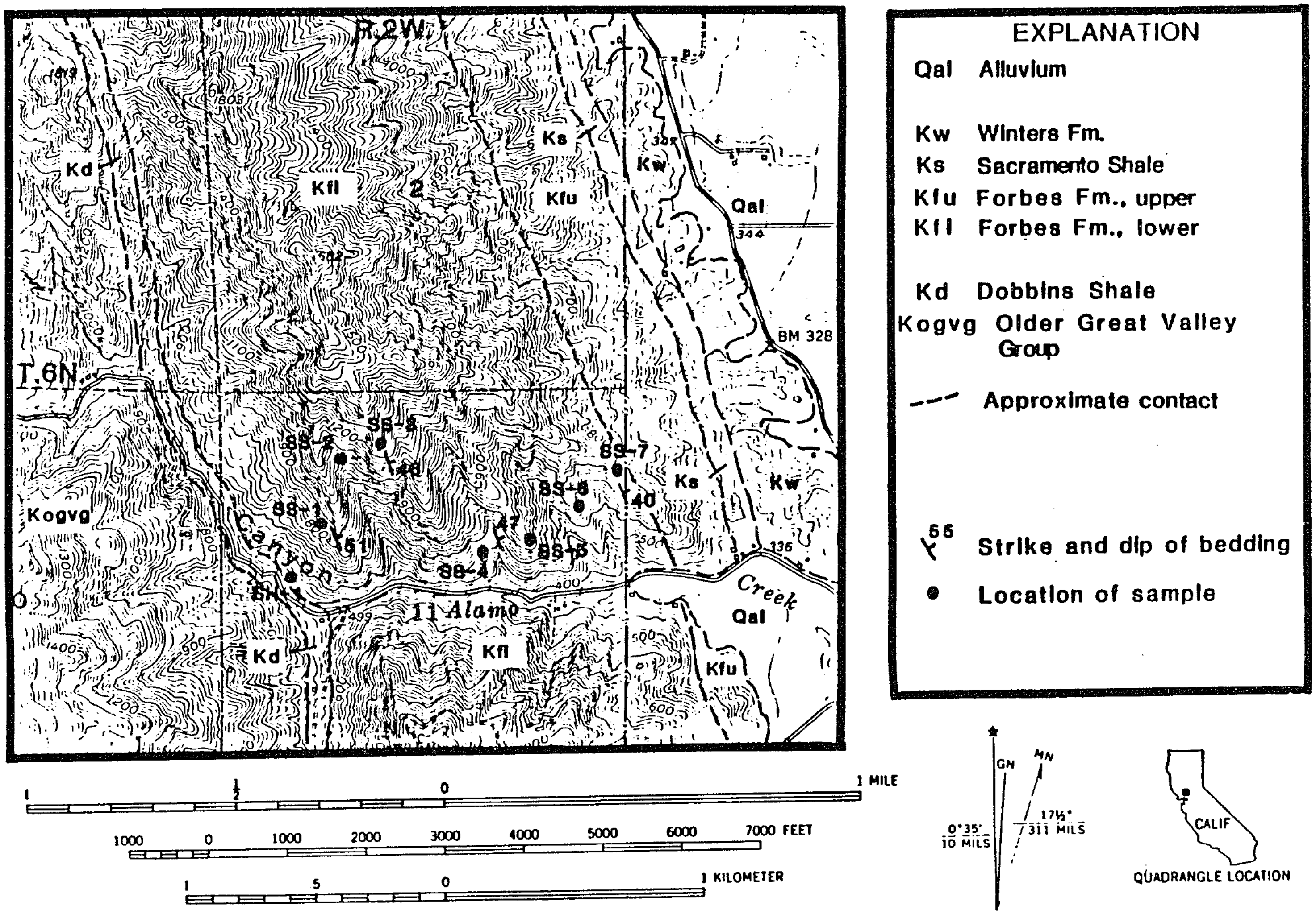
Shell Oil Company drilled thirty overlapping diamond core holes through 15,500 ft (4700 m) of section along Putah Creek in 1951 (Stinemeyer, 1979). The goal of this effort was to obtain good quality samples for paleontologic analysis to resolve correlation problems. The cores later were made available at the California Well Repository in

Figure 5. Simplified geologic map modified from Emerson and Roberts (1962) and Trosper (1985) of the Putah Creek measured section area showing locations of sandstone and shale samples and key Shell diamond core holes. Base map is the Monticello Dam 7.5-minute topographic quadrangle.



EXPLANATION
Qal Alluvium
Teu Eocene undifferentiated
Kw Winters Fm.
Ks Sacramento Shale
Kfu Forbes Fm., upper
Kfl Forbes Fm., lower
Kd Dobbins Shale
Kogvg Older Great Valley Group
Approximate contact
Strike and dip of bedding
Location of sample
Location of diamond core holes
R.2W.
T.8N.
Kogvg
Kd
Kfl
Kfu
Teu
Ks
Kw
Qal
SH-1
SS-1
SS-2
SS-3
SS-4
SS-5
SS-6
SS-7
SH-2
SH-3
A1
A1A
A2
A3
A6
A7
B5
B6
C1
CREEK
YOLO
SOLANO
M O U N T A I N S
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
GN
MN
0°35' 10 MILS
17½° 311 MILS
CALIF
QUADRANGLE LOCATION

Figure 6. Simplified geologic map modified from Emerson and Roberts (1962) of the Gates Canyon measured section area showing locations of sandstone and shale samples. Base map is Mt. Vaca 7.5-minute topographic quadrangle.



R.2W.
T.6N.
Kd
Kfl
Ks
Kfu
Kw
Qal
Kogvg
BM 328
SS-1
SS-2
SS-3
SS-4
SS-5
SS-6
SS-7
Canyon
Alamo
Creek
EXPLANATION
Qal Alluvium
Kw Winters Fm.
Ks Sacramento Shale
Kfu Forbes Fm., upper
Kfl Forbes Fm., lower
Kd Dobbins Shale
Kogvg Older Great Valley Group
Approximate contact
Strike and dip of bedding
Location of sample
1 MILE
7000 FEET
1 KILOMETER
GN
MN
0°35' 10 MILS
17½° 311 MILS
CALIF
QUADRANGLE LOCATION

Figure 7. Simplified geologic map modified from Emerson and Roberts (1962) and Sims and others (1971) of the Cannon Hills area showing locations of sandstone and shale samples. Base map is Fairfield North and Elmira 7.5-minute topographic quadrangles.

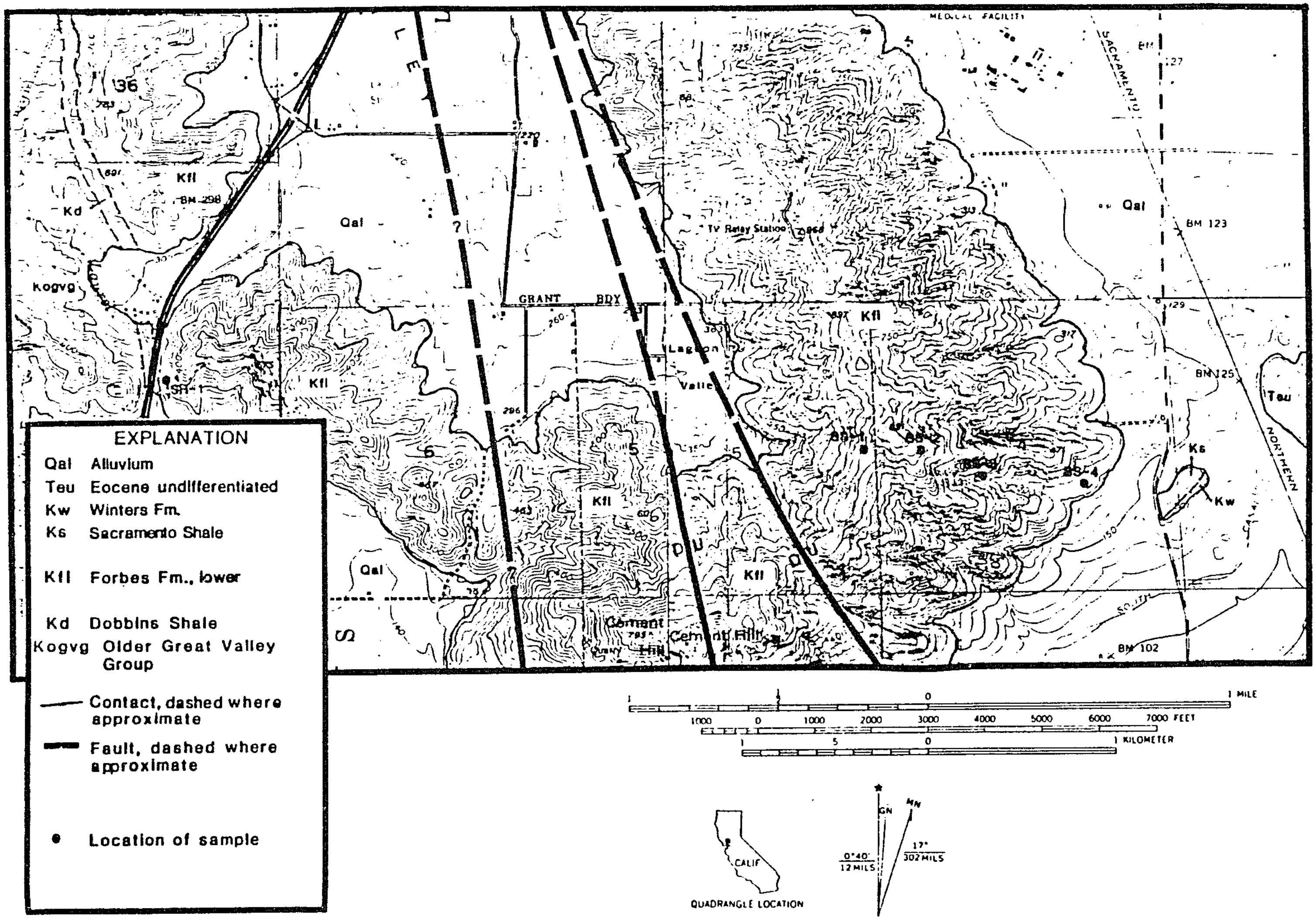
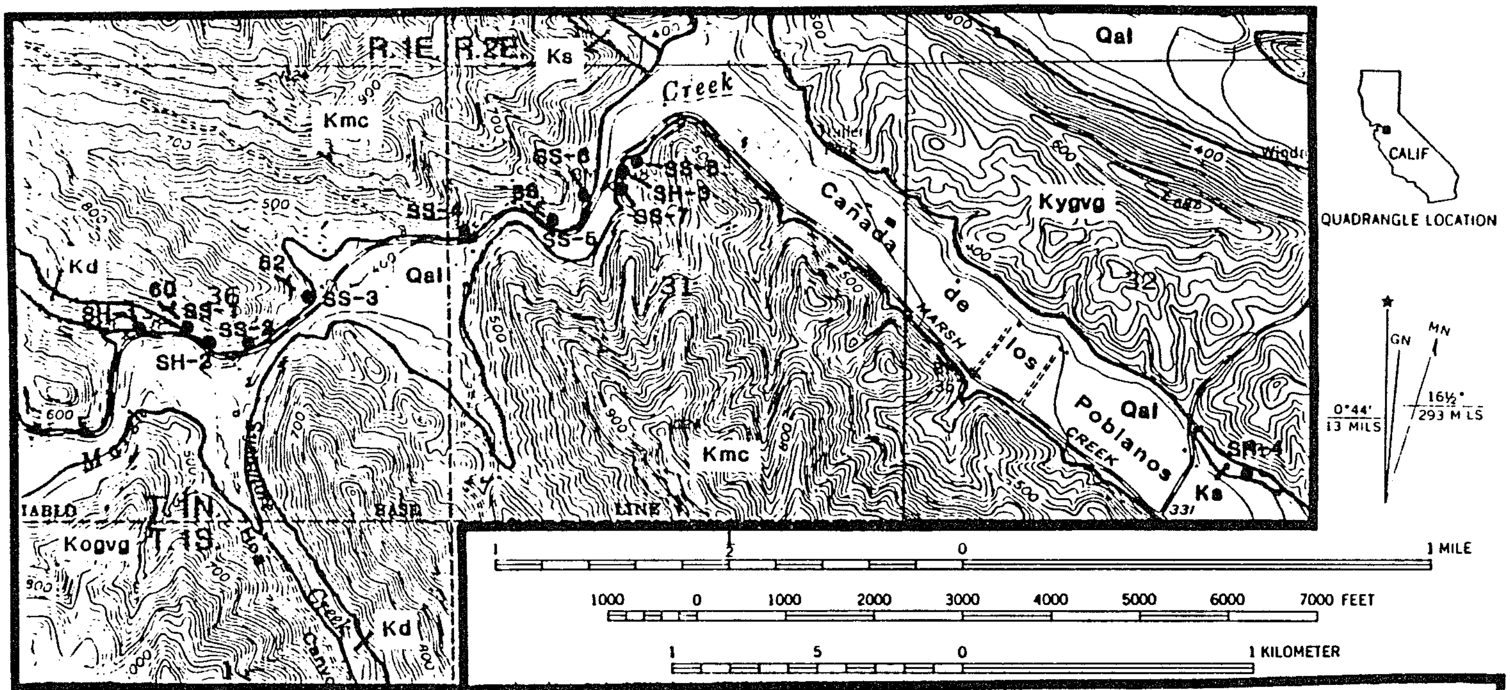

EXPLANATION
Qal Alluvium
Teu Eocene undifferentiated
Kw Winters Fm.
Ks Sacramento Shale
Kfl Forbes Fm., lower
Kd Dobbins Shale
Kogvg Older Great Valley Group
Contact, dashed where approximate
Fault, dashed where approximate
Location of sample
GRANT BDY
TV Relay Station
Lagoon Valley
Cement Hill
MEDICAL FACILITY
SACRAMENTO NORTHERN
BM 123
BM 125
BM 102
BM 298
1 MILE
7000 FEET
1 KILOMETER
QUADRANGLE LOCATION
CALIF
GN
MN
0°40' 12 MILS
17° 302 MILS

Figure 8. Simplified geologic map modified from Colburn (1964) and Cherven and Bodden (1983) of the Marsh Creek measured section area showing locations of sandstone and shale samples. Base map is Antioch South 7.5-minute topographic quadrangle.



EXPLANATION

Qal	Alluvium
Kygvg	Younger Great Valley Group
Ks	Sacramento Shale
Kmc	Marsh Creek Fm.
Kd	Dobbins Shale
Kogvg	Older Great Valley Group

— Contact

85 Strike and dip of bedding

● Location of sandstone or shale sample

Bakersfield and have been used in several biostratigraphic studies (Takayanagi, 1965; Trosper, 1985; Almgren, 1986).

Almgren (1986) used benthic foraminifera to establish correlations from Putah Creek south to the Cannon Hills. His correlations suggest that a complete F-zone section, bounded by the Dobbins Shale Member (G-1 zone) and Sacramento Shale (Lower E zone), is present at both of these localities. Almgren also shows that the F-1 zone, present along Putah Creek, pinches out southward north of the Cannon Hills. Trosper (1985) divided the Forbes Formation into a lower, middle, and upper member along Putah Creek using combined data obtained from the study of planktonic and benthic foraminifera, and calcareous nannofossils. The work of Almgren (1986) and Trosper (1985) generally supports the mapping of Emerson and Roberts (1962) from Putah Creek to the Cannon Hills.

The calcareous nannofossils examined from the Shell diamond core hole samples (Trosper, 1985) showed that the base of the Dobbins Shale Member and the top of the underlying sandstone-dominated Guinda Formation occurs near the top of core C-1 (fig. 5). The boundary between the Campanian (F zone) and the Santonian (G-1 zone) was shown to occur between cores B-5 at 520 ft and B-6 at 105-108 ft. Cores A-1 through A-3 at 142 ft, near the top of the section, were assigned to the *P. ovalis* zone of Miller

(1983) based on superposition. Samples from the Sacramento Shale (Lower E zone) in the northeastern Diablo Range also are assignable, in part, to the P. ovalis zone.

Data at the California Well Repository from Shell's original paleontologic analysis provide additional control. The F-1/F-2 boundary is shown to occur between cores A-6 and A-7 (fig. 5). This contact corresponds to the boundary between the middle and upper members of the Forbes Formation of Trosper (1985).

Five additional samples from the Coast Ranges north of Vacaville were analyzed for foraminifera and calcareous nannofossils to supplement the previous biostratigraphic work and improve mapping (table 1). Two of the three samples from along Putah Creek (fig. 5) provided useful age control. Sample SH-1 contained foraminifera indicating the basal F-2 zone or uppermost G-1 zone (early Campanian to latest Santonian). The diagnostic species in this sample include Psammosphaera laevigata, Cribrostomoides cretacea (large variety), Eponides bandyi, Trochammina boehmi, and Stensioina exsculpta.

Sample SH-3 from Putah Creek collected above the unconformable Upper Cretaceous/Tertiary boundary contained calcareous nannofossils that suggest a middle Eocene age (fig. 5, table 1). Poorly preserved specimens of Discoaster bifax, Nannotetrina quadrata, Reticulofenestra samudorovi, and Helicospaera seminulum, indicating the

Sample Location and Number	Foraminifera	Calcareous Nannofossils
Putah Creek		
SH-1	Stage: Early Campanian to Latest Santonian Zone: Basal F-2 or G-1	Barren
SH-2	Barren	Barren
SH-3	Indeterminate	Age: Middle Eocene Zone: CP13/CP14a of Okada and Bukry (1980)
Gates Canyon		
SH-1	Stage: Early to middle Campanian Zone: F-2	Barren
Cannon Hills		
SH-1	Stage: Early to middle Campanian Zone: F-2	Barren
Marsh Creek		
SH-1	Barren	Stage: Late Santonian Zone: Indeterminate
SH-2	Barren	Barren
SH-3	Barren	Barren
SH-4	Stage: Campanian Zone: Lower E	Stage: Middle Campanian Zone: *Quadrum nitidum* of Sissingh (1977)

Table 1. Biostratigraphic data from analysis of foraminifera and calcareous nannofossils from outcrop samples (sample locations on Figures 5-8).

CP13/CP14a zones of Okada and Bukry (1980), are present. Overlap of N. quadrata and D. bifax is indicative of the middle Eocene Nortonville and Lower Markley Shale, supporting the mapping of Brooks (1962a,b).

Samples SH-1 from Gates Canyon and SH-1 from the Cannon Hills (figs. 6 and 7, table 1) both contained foraminifera indicative of the F-2 zone (early to middle Campanian). Characteristic fossils in these samples include Psammophaera laevigata, Bathysiphon perampla, and Cribrostomoides cretacea (large variety). These samples helped to define the base of the F-zone strata, which is slightly different than that suggested by the mapping of Emerson and Roberts (1962).

Northeastern Diablo Range

Colburn (1961, 1964) established the approximate limits of the F-zone strata of Goudkoff (1945) in the vicinity of Marsh Creek near Mount Diablo from the analysis of twelve samples. Almgren (1986) also recognized the G-1 zone and the Lower E zone, the "white radiolarian shale" of Colburn (1961), bounding the F zone in the vicinity of Mount Diablo. His work showed that the F-1 zone is not present in this area or the Cannon Hills area.

Two of four additional samples taken from along Marsh Creek for this study (fig. 8, table 1) provided important age control to supplement the work of Colburn (1961, 1964) and Almgren (1986). Sample SH-1 contained calcareous nannofossils including poorly preserved specimens of Watznaueria barnasea, Marthasterites furcatus, Micula staurophora, Eiffellithus eximius, Zygodiscus diplogrammus, and Chiastozygus litterareus that indicate a late Santonian age. This assemblage is diagnostic of the Dobbins Shale Member near its type locality at Salt Creek (Filewicz, 1986). Sample SH-4 (fig. 8) contained both foraminifera and calcareous nannofossils that indicate middle Campanian Lower E zone. Diagnostic foraminifera species include Anomalina henbesti, Globotruncana churchi, and Gyroidina quadrata. Calcareous nannofossils indicate the Quadrum nitidum zone (middle Campanian) of Sissingh (1977); abundant, moderately preserved specimens of W. barnasae, M. staurophora, Quadrum nitidum, Ceratolithoides aculeus, Broinsonia cf. parca, and Reinhardtites anthophorous are present. This assemblage correlates with a portion of the Sacramento Shale at its exposure in the Cannon Hills (Filewicz, 1986).

Subsurface

Subsurface biostratigraphic correlations are based on data from six wells. Data from four wells have been presented in the published literature (Almgren, 1986); two wells are from previously unpublished paleontologic reports. Four of these wells are displayed on the regional stratigraphic cross sections (plates 7-9); and the other two are correlated with a well on a regional stratigraphic cross section (plate 8).

Almgren (1986) showed that Occidental Petroleum Corp. Mumma #1 (sec. 1, T.12N., R.1W.) and Arbuckle Unit S #1 (sec. 4, T.13N., R.2W.) contain complete F-zone sections, more than 5000 ft (1500 m) thick, with about equal thicknesses of F-1 and F-2 zones. These rocks are underlain by G-1-zone rocks and overlain by Lower E-zone rocks. The biostratigraphic data from these two wells are correlated with the Alta Petroleum, Nelson #1-6 (sec. 6, T.12N., R.2E.) on regional cross section D-D′ (plate 8).

Almgren (1986) showed that the Lower E zone directly overlies the F-2 zone, with the F-1 zone absent, in the Standard Oil Co., Peter Cook #1 (sec. 8, T.4N., R.3E.). Approximately 2000 ft (610 m) of F-2-zone section is present in this well, and at a depth of over 15,000 ft (4600 m) the G-1 zone still had not been penetrated. This is the same relationship demonstrated by Almgren in outcrop between Putah Creek and the Cannon Hills where the F-1 zone pinches out southward. South of the Peter Cook #1 well, Almgren (1986) also showed that the F-1 zone is absent in the Amerada Petroleum Corp., Tracy Community #1 (sec. 15, T.2S., R.5E.) displayed on regional cross section C-C′ (plate 7).

Foraminiferal data for two wells from previously confidential reports provide age control in the southern portion of the basin. Identification of G-1, F, and Lower E zones in the ARCO Oil and Gas Co., Mantelli #1, in section 14, T.1N., R.4E. (plate 8) and Champlin Petroleum Co., Texaco-Chevron-Franzia No. 1-33, in section 33, T.1N., R.8E. (plate 9) provided a basis for well-log correlations and key thicknesses for isopach maps (plate 4).

Discussion

Biostratigraphic data have established chronostratigraphic correlations between the Coast Ranges north of Vacaville, the northeastern Diablo Range, and the subsurface of the southern Sacramento and northern San Joaquin basins. Calcareous nannofossil data from sample SH-1 from Marsh Creek combined with lithologic data suggest that the Dobbins Shale is present in the northeastern Diablo Range. Sample SH-4 from Marsh Creek confirmed that the Sacramento Shale is present to the north in the Coast Ranges north of Vacaville and in the northeastern Diablo Range. The two basinwide shale deposits, the Dobbins Shale (G-1 zone) and Sacramento Shale (Lower E zone) with their distinct microfossil assemblages of foraminifera and calcareous nannofossils, define the limits of the thick F-zone deposits. Almgren (1986) also recognized the southward pinchout of the F-1 zone in both outcrop and subsurface (plate 8).

STRATIGRAPHY AND SEDIMENTOLOGY

Subsurface Stratigraphy

Methods

The understanding of the stratigraphic relationships between the different lower Campanian strata in the southern Sacramento and northern San Joaquin basins was significantly aided by the use of subsurface data. Well logs were used to identify and correlate major stratigraphic units and were the principal source of information for the subsurface analysis. These correlations allowed construction of a series of maps and cross sections that display the important stratigraphic relationships between the Forbes and Marsh Creek Formations (plates 1-9).

Wells were selected for study on the basis of depth of penetration into F-zone strata (minimum of 1000 ft (300 m)), penetration of basement rock, or demonstration of an important stratigraphic or structural relationship. A total of 204 well logs, which were assigned identification numbers and are listed in Appendix 1, were selected. The area from which these wells were selected extends from the northern edge of T.12N. to the southern edge of T.5S. and follows the outline of the valley from R.3W. to R.11E. The wells are plotted on the base map shown on plate 1.

Well-log correlations were developed to display stratigraphic relationships between the Forbes and Marsh Creek formations. Correlated horizons include: (1) top of Cretaceous strata, (2) top of Sacramento Shale, (3) top of Kione Formation, (4) top of F-zone strata, (5) top of Dobbins Shale, and (6) top of basement rocks. Figures 9 and 10 display typical sections of the Forbes and Marsh Creek formations with the underlying Dobbins Shale and overlying Sacramento Shale showing the well-log characteristics of these units. The well-log correlations are included in Appendix 1.

Nine plates display the stratigraphic and structural relationships of the early Campanian strata in the southern Sacramento and northern San Joaquin basins. Four maps (plates 1-4) include, (1) a base map with cross sections, (2) a structure-contour map of top basement rocks, (3) an isopach map of Kione Formation, and (4) an isopach map of F zone. Five cross sections (Plates 5-9) include three east-west sections (A-A′, B-B′, C-C′) and two north-south sections (D-D′, E-E′).

Regional Stratigraphic Units

Basement Complex. The basement complex beneath the Great Valley Group consists of the Sierran igneous and metamorphic magmatic-arc complex exposed to the east, and the Franciscan Assemblage accretionary/subduction complex

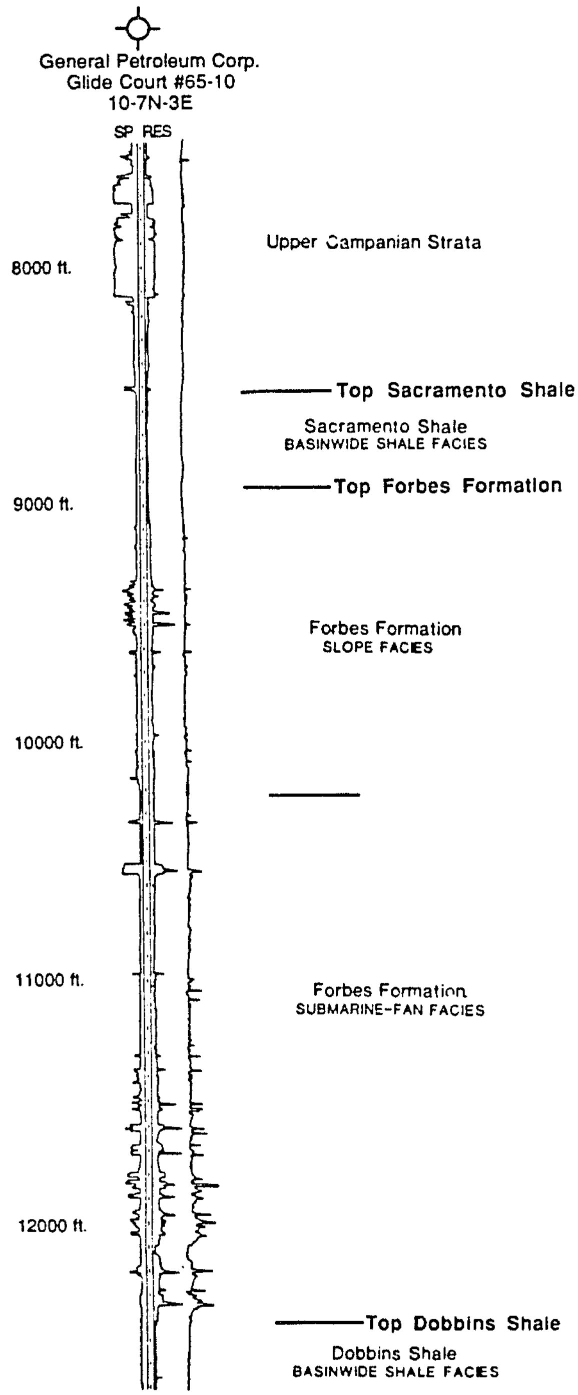


Figure 9. Typical well log for the Forbes Formation (General Petroleum Corp., Glide Court #65-10, sec. 10, T.7N., R.3E.).

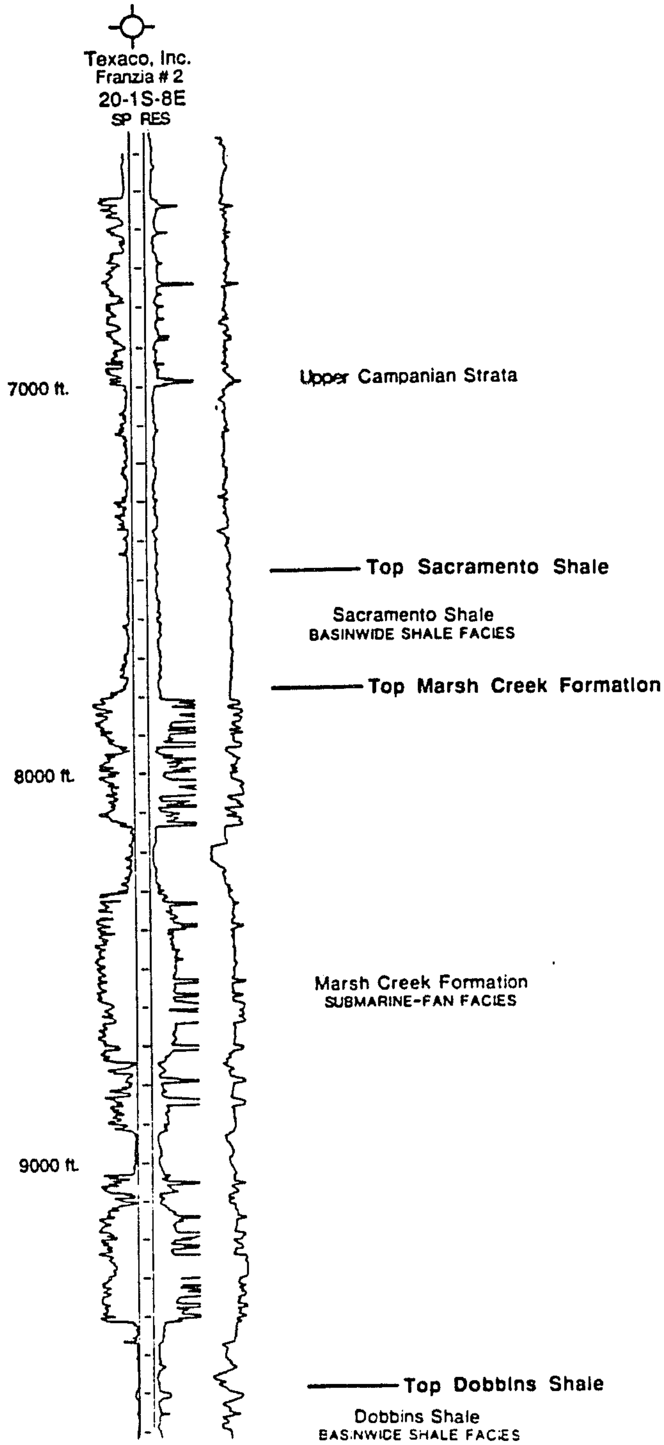


Figure 10. Typical well log for the Marsh Creek Formation (Texaco Inc., Franzia #2, sec. 20, T.1S., R.8E.).

exposed to the west. The location of the contact between these two basement types beneath the thick sedimentary sequence has not been determined. Seventy-nine studied wells penetrate the basement complex, the majority being along the eastern margin of the basin where they penetrate the Sierran basement. A structure-contour map was prepared on the top of the known basement surface (plate 2).

Four main faults or fault complexes offset the basement surface. These include (1) the Freeport fault, (2) the Thornton fault, (3) the Stockton fault complex, and (4) the Modesto fault. These faults have a general east-west to northeast-southwest orientation, perpendicular to the strike of the basement surface. The Freeport fault, located in T.7N., R.4-7E., is downthrown to the north with displacement exceeding 1000 ft (305 m). The Thornton fault, located in T.4N., R.6-8E., is downthrown to the north with a maximum offset of only a few hundred feet. The Stockton fault complex has been mapped as consisting of two major faults. The main fault is along T.1-2N. and extends from R.5E. to east of R.8E. The smaller fault, which may also continue to the east, is located a few miles north of the main fault in T.2N., R.7-8E. These faults are down to the south (plate 9), the main fault showing more than 2000 ft (610 m) of vertical displacement and the second fault more than 1000 ft (305 m). The Modesto fault is located in T.2-4S. and R.8-11E. and is downthrown to the north with almost 2000 ft (610 m) of offset.

The F-zone strata show significant increases in thickness north of the Freeport fault and between the Stockton fault complex and the Modesto fault (plate 4). The thickness of F-zone strata between the Stockton fault complex and Modesto fault suggests a large subbasin, here named the Stockton subbasin. These F-zone isopach values indicate that the timing of the basement faulting is Campanian and/or pre-Campanian (plate 4).

The Stockton arch has been documented as being bounded by a high-angle fault along the northern margin that was active in the late Paleocene with over 2000 ft (610 m) of reverse down-to-the-north displacement (Callaway, 1964; Teitsworth, 1968). This feature forms the present-day boundary between the Sacramento and San Joaquin basins. Subsurface stratigraphic relationships show that the main Stockton fault may have had as much as 4000 ft (1220 m) of Late Cretaceous down-to-the-south displacement based on differences in thickness of the Campanian sedimentary section on opposite sides of the fault (plate 9). This suggests that the Stockton fault has a polyphase history, a Late Cretaceous phase and the previously documented late Paleocene phase. The basement structure map (plate 2), F-zone isopach map (plate 4), and cross section E-E′ (plate 9) all suggest Late Cretaceous down-to-the-south displacement.

<u>Older Great Valley Group</u>. This group includes all units older than the Dobbins Shale. This nomenclature is used on the five regional cross sections (plates 5-9) where no attempt was made to subdivide the pre-Dobbins Shale units. This sequence includes the Cenomanian to mid-Santonian Fiske Creek, Venado, Yolo, Sites, Funks, and Guinda Formations, mapped in the Coast Ranges by Kirby (1943). The older Cretaceous strata span the J-1 to G-1 foraminiferal zones (Almgren, 1986).

<u>Dobbins Shale</u>. The Dobbins Shale is an upper Santonian basinwide shale unit deposited during a time of relative sea-level rise or highstand, when coarse sediment was trapped in shallow-marine environments (Imperato and others, 1990). The Dobbins Shale generally has been included as a member of the Forbes Formation (Imperato and others, 1990). However, because this unit is lithologically distinct, and because biostratigraphic and subsurface correlations show that this unit also underlies the Marsh Creek Formation in the northeastern Diablo Range and south of the Stockton fault in the subsurface, the Dobbins Shale probably should be raised to formational status. The Dobbins Shale represents a "condensed" stratigraphic interval of pelagic and hemipelagic shale, probably representing a good time-stratigraphic unit. The

top corresponds to the G-1 - F-zone boundary (fig. 4). The Dobbins Shale represents both basin-plain and marginal-slope facies associations, and possibly a shelf facies along the easternmost margin of the basin (Imperato and others, 1990).

The top of the Dobbins Shale was used for correlation of well logs to define the base of the F-zone strata (Appendix 1). On well logs the Dobbins Shale is represented by a low-resistivity log response (figs. 9 and 10). This unit ranges in thickness from 200 ft (60 m) to 500 ft (150 m) in the basin depocenter to less than 50 ft (15 m) along the eastern margin of the basin. To the east, the Dobbins Shale is onlapped by the F-2-zone Forbes Formation submarine-fan facies (plates 5 and 6). This relationship suggests the presence of a basin-margin unconformity (Imperato and others, 1990).

Forbes Formation. The Forbes Formation was deposited as a mud-rich submarine fan-slope turbidite system fed by the Kione delta system that prograded southward down the plunging axis of the forearc basin (Imperato and others, 1990). The Forbes Formation is early Campanian in age and corresponds to the F zone of Goudkoff (1945). This unit can be divided into submarine-fan and slope facies associations which, in the subsurface, are recognized by their depositional facies, well-log signatures, biostratigraphic zones, seismic facies, and sandstone distribution (Imperato and others, 1990).

The Forbes Formation is more than 6000 ft (1800 m) in thickness in T.9-12N. R.1W. and thins to less than 2000 ft (600 m) in T.3N. (plate 4). This thinning can be attributed to the pinching out of the Kione delta system along the T.8-9N. border (plate 3). The Kione delta provided the sediment to the Forbes Formation; once this system shut off, Forbes deposition ceased. In the depositional axis of the basin, the contact between the Forbes Formation and Dobbins Shale is conformable. To the east the Forbes Formation gradually thins until it grades into the shelf deposits represented by part of the Chico Formation. This eastward thinning can be attributed to the onlap of the submarine-fan and slope deposits onto the Dobbins Shale along a basin-margin unconformity (plates 5 and 6).

The Forbes Formation was divided into submarine-fan and slope facies associations on three of the regional stratigraphic cross sections (plates 5, 6, and 8). The boundary between these two facies associations is based on well-log signatures (fig. 9), biostratigraphic zones, and sandstone distribution.

The submarine-fan facies association consists of a series of stacked channel-levee sequences. The channel-levee sequences range in thickness from 100 ft (30 m) to

500 ft (150 m) and form thickening-upward and then thinning-upward vertical symmetrical cycles (Imperato and others, 1990). These symmetrical cycles represent laterally migrating channel-levee sequences. The lower part of each sequence represents levee deposits that thicken upward. These are overlain by channel and channel-margin deposits that have blocky and thinning-upward log responses (fig. 9). The submarine-fan facies (see cross section D-D′ on plate 8) corresponds to the F-2 zone of Goudkoff (1945).

The slope facies association, which conformably overlies the submarine fan, is represented by shale-rich deposits that are cut by laterally discontinuous sandstone- and conglomerate-filled gully systems. The overall percentage of sandstone is less in the slope because there are fewer gully deposits in the slope compared to channel-levee complexes in the submarine fan. These gully systems acted as conduits to transport sediment from the Kione delta system to the submarine fan. Cross sections A-A′ and B-B′ (plates 5 and 6) show the slope facies as laterally equivalent to the shelf deposits of the Chico Formation to the east. Conformably overlying the Forbes slope deposits is the Kione delta which pinches out along the border between T.8-9N. South of here the Sacramento Shale conformably overlies the slope deposits. Gully sandstones typically are fining-upward or have blocky or ratty log signatures (fig. 9). Gully deposits range in thickness from less than 50 ft (15 m) up to 500 ft (150 m); however, most complexes are on the order of 100 ft (30 m) to 200 ft (60 m) thick. The sandstone-to-shale ratios of the slope facies are typically less than those of the submarine-fan facies association. Because the gully systems acted as conduits to transport sediment, coarse material may not have accumulated within the gullies and some of these were later filled with hemipelagic shale. The slope facies association and the Kione Formation were formed during the F-1 zone of Goudkoff (1945), as demonstrated by biostratigraphic data (see cross section D-D′ on plate 8). South of the pinchout of the Kione delta, the slope deposits gradually thin until they pinch out in the vicinity of T.4-5N.

Kione Formation. The Kione Formation is the deltaic system that conformably overlies the Forbes Formation slope facies association north of T.8-9N.; it provided the sediment to the prograding Forbes depositional system. Resting conformably above the Kione Formation is the Sacramento Shale. An isopach map of the Kione Formation (plate 3) shows a maximum thickness of almost 500 ft (150 m) in T.12N., R.1W. In the central Sacramento basin, this unit reaches thicknesses of more than 1000 ft (300 m). The isopach map shows four main north-south-oriented deltaic lobes that pinch out between T.7N. and T.9N. This north-south orientation and the termination to the south suggest that the Kione delta system prograded from the north (plates 3 and 8). The lobate nature of this system suggests that it is a fluvial-dominated system (Galloway, 1975). The Kione Formation is truncated to the east and west in the subsurface by regional unconformities and locally by the Oligocene Markley Canyon fill (Almgren, 1984) in the vicinity of T.12N., R.4-5E. The Kione is made up of a series of delta-front packages that have coarsening- and thickening-upward log signatures (plates 5 and 8). Mud-rich prodelta deposits are included in the Forbes Formation slope facies.

Marsh Creek Formation. The Marsh Creek Formation is a submarine-fan system that is not documented in the subsurface in published literature. Published information concerning the Marsh Creek Formation has been derived from outcrops in the northeastern Diablo Range. This unit is of early Campanian age (F zone) and thus is the same age as the Forbes Formation. The basement structure map (plate 2) and the F-zone isopach map (plate 4) suggest that the Stockton subbasin was the depositional site of this system. Subsurface control for the Marsh Creek is very sparse with the exception of a few wells near the eastern margin of the basin and along the outcrop belt. It is unclear if the

Marsh Creek Formation is restricted to the Stockton subbasin or if it extends farther to the south.

Subsurface information from the eastern margin of the basin in T.1N.-1S., R.8E. indicates the presence of a series of thick east-west-oriented sandstone packages (plates 7 and 9). The sandstone packages range in thickness from 100 ft (30 m) to 500 ft (150 m) and are characterized by blocky to fining-upward log signatures (fig. 10). These sandstones may represent a series of stacked submarine-canyon deposits cutting through slope deposits. The Marsh Creek Formation does not appear to have an associated deltaic system; therefore, it probably was fed directly by sediment transported through these large submarine canyons.

Chico Formation. The Chico Formation includes the shelf deposits of F-zone age that are equivalent to the Forbes and Marsh Creek Formations along the eastern margin of the basin. The approximate limits of this unit are defined on the F-zone isopach map (plate 4). The basinward lateral equivalent of this unit in the southern Sacramento basin is the Forbes Formation slope facies (plates 5 and 6). The Chico Formation generally rests directly upon or just above the Sierran basement and ranges in thickness from over 700 ft (200 m) to less than 100 ft (30 m). This unit shows a variety of blocky, ratty, coarsening- and fining-upward log signatures (plates 6 and 9). Upper slope, shoreface, deltaic, and fluvial deposits all probably are represented in the Chico Formation.

Sacramento Shale. The Sacramento Shale is a mid-Campanian basinwide shale that probably was deposited during a relative sea-level rise or high stand (Nilsen, 1990). This unit represents a "condensed" stratigraphic interval of pelagic and hemipelagic deposits. The Sacramento Shale has been documented paleontologically as a good time-stratigraphic marker and therefore serves as the stratigraphic datum on four of the regional stratigraphic cross sections (plates 5-8). This unit corresponds to the Lower E zone, defined by a very distinct microfossil assemblage (Almgren, 1986). The Sacramento Shale represents basin-plain deposition in the southwestern portions of the basin, and slope and shelf deposition to the north, northeast, and east.

The Sacramento Shale overlies the Kione, Forbes, and Marsh Creek formations, its base marking the top of the F zone. The Sacramento Shale generally is easy to recognize and is correlated in well logs on the basis of its low-resistivity response and uniform thickness within the basin (figs. 9 and 10). Thicknesses range from 200 ft (60 m) to 400 ft (120 m) within the basin to less than 50 ft (15 m) along the basin margins. The top of the Sacramento Shale was used for regional well-log correlations and are included in Appendix 1.

Upper Campanian and Maestrichtian Strata. Upper Campanian and Maestrichtian strata include a series of submarine-fan/slope/delta systems separated by basinwide shale units (Moore and Nilsen, 1990). These units represent the final phase of Cretaceous marine sedimentation in the Great Valley forearc basin. Submarine-fan/slope units include the Winters, Lathrop, Tracy, and Blewett formations. Deltaic units include the Starkey, Mokelumne River, and Garzas formations. Basinwide shale units include the Sawtooth, Ragged Valley, H&T, and Hall shales. The upper Campanian and Maestrichtian strata are included in the E, D-2, D-1, and C zones of Goudkoff (1945). The Sawtooth Shale was used as the stratigraphic datum on cross section E-E′ (plate 9) to show the increased thickness of the entire Campanian interval within the Stockton subbasin.

Post-Cretaceous Unconformities. Four major post-Cretaceous unconformities that truncate the Campanian and Maestrichtian strata are shown on the five regional cross sections (plates 5-9). These include unconformities at the base of: (1) the Capay Formation, (2) the Markley Canyon fill, (3) the Valley Springs-Mehrten Formation, and (4) the Tehama Formation. The Capay Formation is a shallow-water marine shale with a basal sandstone unit (Cherven, 1983); it ranges in thickness from 100 ft (30 m) to more than 500 ft (150 m). The Markley Canyon was cut in the late Eocene and filled primarily with hemipelagic mud in the Oligocene. This cut and fill was related to a cycle of tectonism, erosion, and relative sea-level rise (Almgren, 1984). The Valley Springs and Mehrten formations are composed of nonmarine sandstone, conglomerate, and shale (California Division of Oil and Gas, 1982) that reflect erosion of Miocene volcanics in the Sierra Nevada. The Tehama Formation is a Plio-Pleistocene unit composed chiefly of nonmarine sandstone and gravel in the Sacramento Valley.

Outcrop Stratigraphy and Sedimentology

Methods

Three stratigraphic sections of F-zone strata were measured (Appendix 2), two in the Coast Ranges north of Vacaville and one in the northeastern Diablo Range. Sections measured in the Coast Ranges are in sections 22, 23, and 27, T.8N., R.2W., just north of Putah Creek (fig. 5), and in sections 11 and 12, T.6N., R.2W., just north of Gates Canyon (fig. 6). These sections were selected because of the presence of a complete F-zone interval from the top of the Dobbins Shale to the base of the Sacramento Shale. Maps by Emerson and Roberts (1962) and biostratigraphic control also were considered when selecting these sections. North of Putah Creek the Sacramento Shale and upper Forbes Formation are truncated so that these sections are not complete. South of Gates Canyon the Forbes Formation is structurally complicated in the Cannon Hills area (fig. 7). The section measured in section 36, T.1N., R.1E. and section 31, T.1N., R.2E. in the northeastern Diablo Range is along Marsh Creek (fig. 8). This section was selected because of the presence of a complete section, biostratigraphic control, quality of the exposures, and accessibility.

All three sections were measured using a 1.5-m Jacob staff, and all sandstone and shale beds were measured and described in detail. Beds less than 3 cm thick were measured and described with adjacent beds. Covered intervals were measured and included in the descriptions. Descriptions for sandstone and shale beds include the features of the Bouma (1962) divisions and the turbidite facies of Mutti and Ricchi Lucchi (1972). Descriptions also include sedimentary features that were thought to be significant in making interpretations. Special attention was focused on measurement of paleocurrent indicators, principally flute and groove casts. All paleocurrent measurements from one bed were averaged so that each individual bed is shown as having only one paleocurrent measurement.

Putah Creek Measured Section

The F-zone (Forbes Formation) section along Putah Creek (fig. 5) is 1604 m (5262 ft) in thickness (Appendix 2). The outcrop belt has a general north-south trend, the average strike is about 173 degrees, and the dips range from 69 degrees east at the base of the section to 55 degrees east at the top. The outcrops consist of thick, competent sandstone packages forming north-south-trending ridges with intervening canyons underlain by poorly exposed strata (fig. 11). The upper portion of the section has a significantly lower ratio of sandstone to shale/covered interval than the lower part. The lower 1010 m (3314 ft) of section has 18% sandstone and the upper 594 m (1949 ft) of section has 5% sandstone.

Sandstone bodies range in thickness from a few meters to up to 30 m (100 ft), and commonly are discontinuous along strike. They consist of amalgamated or closely interbedded sandstone beds, ranging in thickness from a few centimeters up to 7 m (23 ft). Sandstones are dominantly medium grained and fine upward to very fine sandstone or siltstone for the upper 10 percent of the bed. Sandstone bodies display both thickening- and thinning-upward sequences as well as packages with no apparent trend. Individual beds commonly have erosive bases with flat tops and show lateral thickness variations. Sandstone beds are

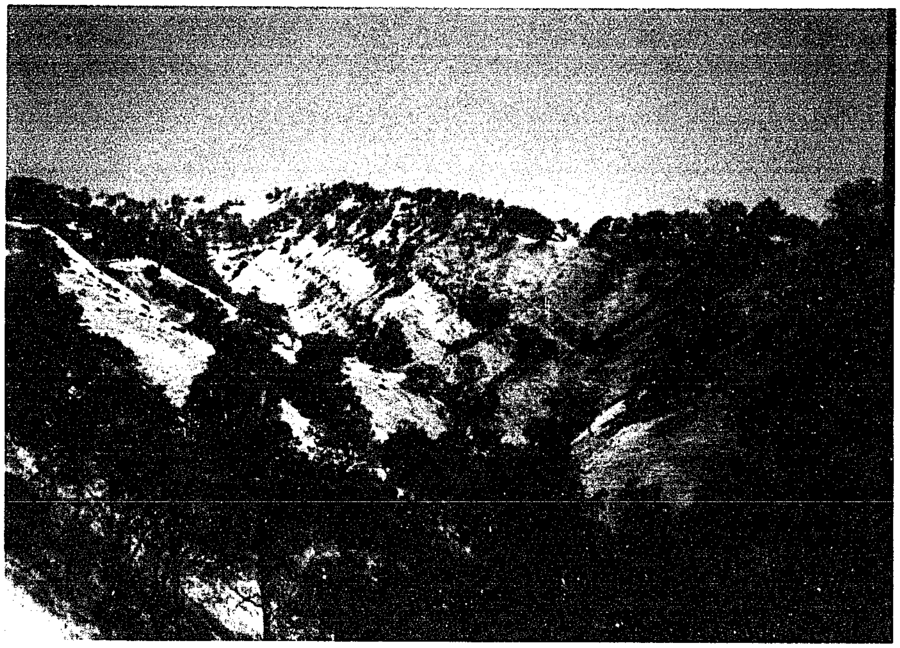


Figure 11. View northward of east-dipping sandstone bodies of the Forbes Formation forming a prominent ridge north of Putah Creek (SE1/4 sec. 22, T.8N., R.2W., Monticello Dam 7.5-minute topographic quadrangle).

graded and show the Ta, Tab, or Tabc Bouma divisions and are classified as Facies B of Mutti and Ricchi Lucchi (1972).

The Facies B beds show a wide range of sedimentary features in addition to the massive, planar laminated, and ripple laminated subdivisions of the Bouma Tabc sequence. The Tc division locally is characterized by convolute or wavy subparallel laminations (fig. 12) instead of the typical ripple laminations. Shale rip-up clasts near the base of beds are fairly common. Flame structures also are typical at sandstone-shale-bed boundaries, indicating loading and dewatering. Dish and pillar structures within Facies B beds are additional evidence of dewatering of sandstones during deposition (fig. 12). Rare shell fragments are associated with Ta subdivisions in Facies B beds. Concretions are common and are distributed laterally within a bed or localized as "cannonball" concretions.

Shale intervals also contain thinly bedded, discontinuous sandstone and siltstone beds ranging in thickness from 1 to 10 cm (0.4 to 4 in). These beds show the Tc Bouma division, and are classified as Facies E of Mutti and Ricchi Lucchi (1972). Towards the top of the section at 1350 m, two beds composed of shale rip-up clasts supported in a sandstone matrix form the base of two sandstone bodies. These beds are laterally discontinuous and are classified as Facies A of Mutti and Ricchi Lucchi

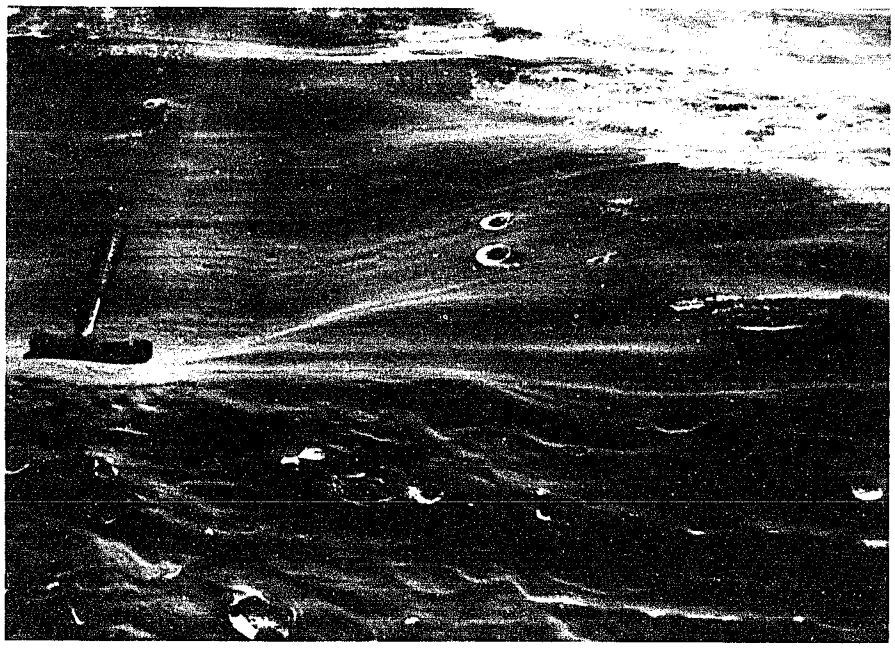


Figure 12. Amalgamated Facies B sandstones of the Forbes Formation showing wavy laminations, scour, and dish structures from the Putah Creek measured section (SW1/4 sec. 22, T.8N. R.2W., Monticello Dam 7.5-minute topographic quadrangle).

(1972). Rare Facies C and D beds occur within thick covered or shale intervals.

Thirty groove and flute casts were measured on eighteen different sandstone beds in the vicinity of the Putah Creek measured section. All flute casts suggest a general southerly transport direction; therefore, the bidirectional groove casts of similar trend are inferred to reflect a similar paleocurrent direction. The mean paleocurrent measurement is 163 degrees with a range from 132 to 185 degrees indicating a south-southeast transport direction (fig. 13).

Gates Canyon Measured Section

The F-zone section (Forbes Formation) just north of Gates Canyon (fig. 6) is 1202 m (3942 ft) thick (Appendix 2). The section strikes 168 degrees; dips range from 40 to 51 degrees to the northeast. The outcrop is characterized by north-south-trending ridges of thick, resistant sandstone bodies separated by canyons underlain by poorly exposed strata. As in the Putah Creek measured section, the upper portion of this section shows a decrease in sandstone with respect to shale/covered interval. The lower 975 m (3199 ft) of section has 12% sandstone and the upper 227 m (745 ft) has 3% sandstone.

The character of the Gates Canyon measured section is remarkably similar to that at the Putah Creek measured

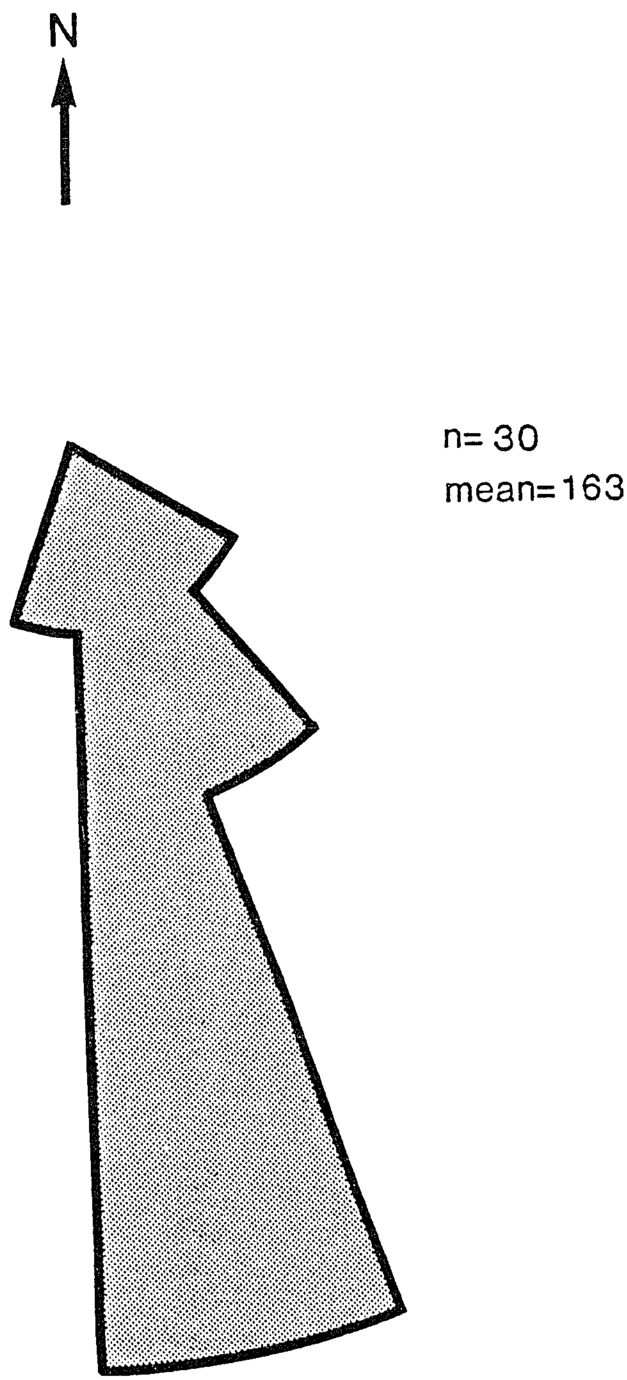


Figure 13. Paleocurrent rose diagram based on Putah Creek data.

section to the north. Sandstones bodies range in thickness from 2 m (7 ft) up to about 12 m (40 ft), with individual beds ranging from a few centimeters to 3 m (10 ft). Sandstone bodies display both thickening- and thinning-upward sequences. These sandstone bodies are dominated by medium-grained Facies B beds with associated Facies E beds (fig. 14).

Facies B beds with erosive bases and lateral thickness variations typically exhibit Bouma Ta, Tab, or Tabc divisions. Additional sedimentary features include shale rip-up clasts, flame structures, convolute laminations, and dewatering structures. Post-depositional features include concretionary beds or "cannonball" concretions. Laterally continuous pinch and swell Facies E beds are typically interbedded with shale (fig. 14). These beds exhibit Bouma Tc divisions and range in thickness from 1-10 cm (0.4 to 4 in).

This section also contains local Facies A conglomerate composed of shale rip-up clasts near the top of the section at 1090 m. Facies C and D beds locally are associated with thick covered or shale intervals.

Eighty flute and groove casts were measured on the base of sixteen different sandstone beds in the vicinity of the Gates Canyon measured section (fig. 15). Flute casts all show a general southerly transport direction similar to the paleocurrents measured at Putah Creek. Groove casts

Figure 14. Forbes Formation Facies B and E sandstones from the Gates Canyon measured section (NW1/4 sec. 11, T.6N., R.2W., Mt. Vaca 7.5-minute topographic quadrangle).

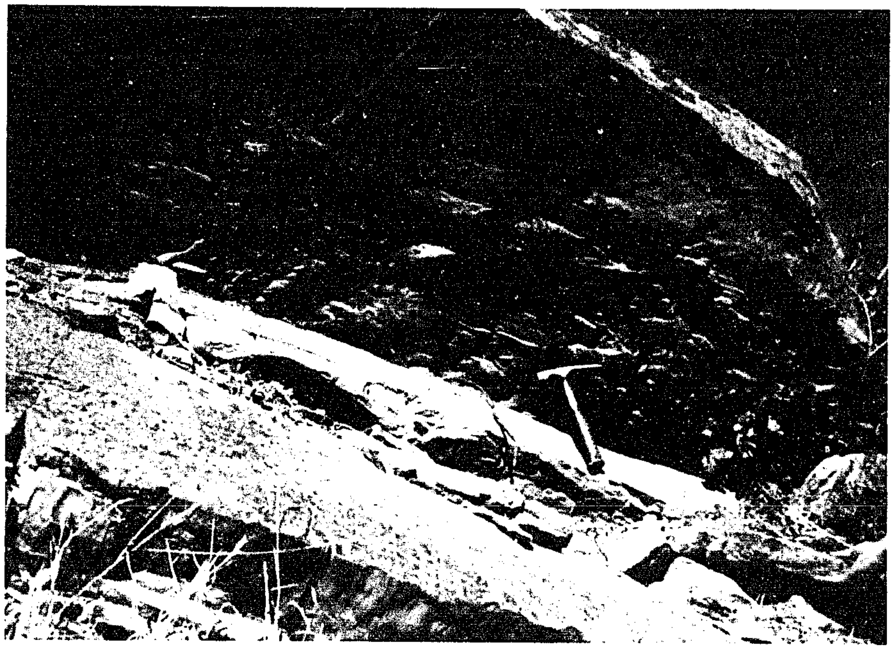


Figure 15. Flute and groove casts at the base of a Forbes Formation Facies B sandstone from along the Gates Canyon measured section (NW1/4 sec. 11, T.6N., R.2W., Mt. Vaca 7.5-minute topographic quadrangle).

have this same trend and are interpreted also to have been formed by south-flowing currents. The mean paleocurrent direction is 180 degrees, with a range from 139 to 245 degrees, indicating a southward transport direction (fig. 16).

Marsh Creek Measured Section

The Marsh Creek section (fig. 8) is 1329 m (4360 ft) thick (Appendix 2). The outcrop belt trends northwest-southeast, with an average strike of 119 degrees. Dips range from 41 to 60 degrees to the northeast, generally shallowing towards the top.

The Marsh Creek measured section can be separated into three distinct sandstone intervals, lower, middle, and upper, separated by thick, covered intervals. The lower interval is 330 m (1083 ft) thick, the lower 135 m (443 ft) of which is dominated by shale and covered sections with relatively few interbedded sandstones. The upper part is dominated by sandstone. Sandstone bodies range in thickness from 2 m (7 ft) up to 15 m (50 ft), with individual beds ranging from a centimeter to more than 7 m (23 ft) thick. In some sequences, sandstone bodies thicken upward (fig. 17); however, most do not have a consistent vertical arrangement. Beds show a wide range of grain sizes, from silt to granule, even within individual sandstone bodies. Sandstones are laterally continuous, and

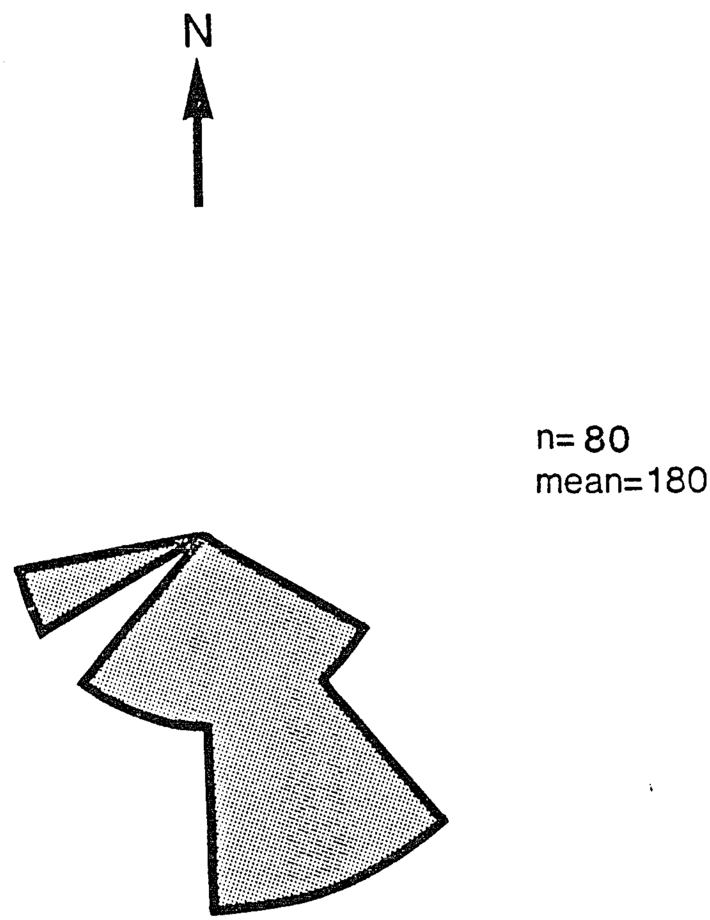


Figure 16. Paleocurrent rose diagram based on Gates Canyon data.

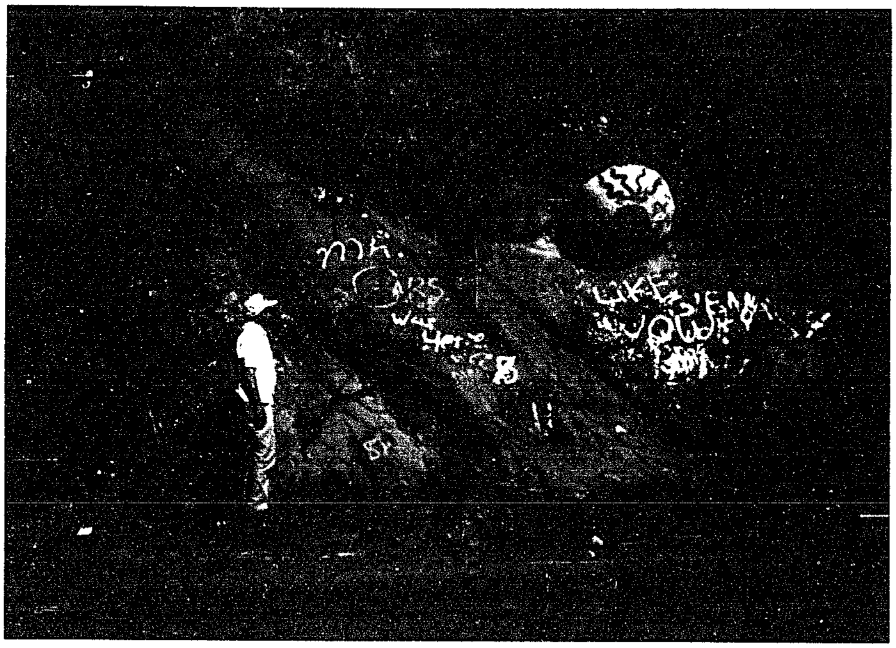


Figure 17. Overall thickening-upward sequence of the Marsh Creek Formation from the Marsh Creek measured section with Dr. Henry J. Moore II for scale (sec. 36, T.1N., R.1E., Antioch South 7.5-minute topographic quadrangle).

typically have sharp bases and tops. Some show minor channels at the base. Beds are normally graded and fine upward to a thin shale parting where not amalgamated (fig. 18). Sandstones show various components of the Bouma divisions (fig. 18) and are classified as Facies C and D beds of Mutti and Ricci Lucchi (1972). Sedimentary features in addition to the Bouma sequences include shale rip-up clasts, convolute laminations, and dewatering structures; biogenic features include burrows and shell fragments; and post-depositional features include concretionary beds and "cannonball" concretions.

The middle interval is 206 m (676 ft) thick and is separated from the lower interval by 492 m (1614 ft) of covered interval. Sandstone bodies range from 2 m (7 ft) to 25 m (80 ft) thick; individual beds range from a centimeter to more than 6 m (20 m). Sandstones are dominantly medium grained, although there are a few siltstones and fine-grained sandstones. Sandstone beds within this interval are assigned to Facies B, D, and E of Mutti and Ricchi Lucci (1972). Facies B beds are normally graded with Bouma Ta, Tab, or Tabc divisions, commonly amalgamated, and channelized (fig. 19). Facies D beds, typically less than 50 cm (20 in) thick, are much thinner than the Facies B beds, lack the Bouma Ta division, and show more lateral continuity. Facies E beds range in thickness from 1 to 10 cm (0.4 to 4 in), are laterally

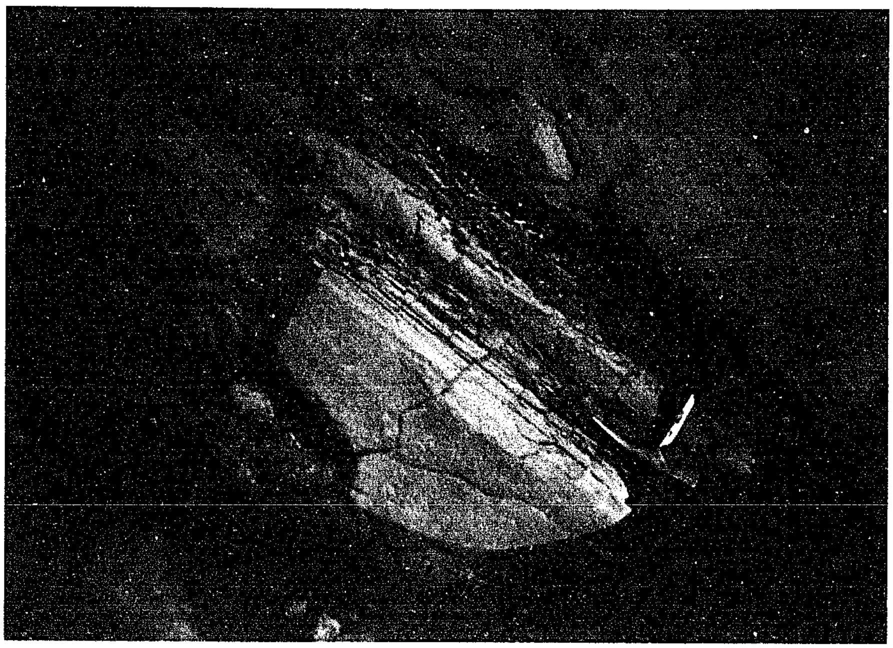


Figure 18. Interbedded Facies C and D sandstones and Facies G shale of the Marsh Creek Formation along the Marsh Creek measured section (sec. 36, T.1N., R.1E., Antioch South 7.5-minute topographic quadrangle).

Figure 19. Amalgamated Facies B sandstones of the Marsh Creek Formation showing scoured surfaces and wavy and convolute laminations along the Marsh Creek measured section (NW1/4, sec. 31, T.1N., R.2E., Antioch South 7.5-minute topographic quadrangle).

discontinuous, and have the Bouma Tc or Tcd divisions. Additional sedimentary features within this interval include shale rip-up clasts, flame structures, convolute laminations, and dewatering structures; biogenic features include burrows and shell fragments; and post-depositional features include concretionary beds.

The upper interval is 101 m (331 ft) thick and is separated from the middle interval by 200 m (656 ft) of covered interval. This upper interval is characterized by thick, coarse- to fine-grained, highly channelized sandstone bodies. The main sandstone body is 42 m (138 ft) thick, with individual Facies A and B beds ranging in thickness from 1.5 to 16 m (5 to 53 ft). These beds are composed of medium to coarse sand; pebbles also are present, but in minor amounts. These beds are separated by intervals of shale with interbedded Facies E sandstone and siltstone. Synsedimentary, deformed Facies F sandstone, siltstone, and shale also were recognized in this interval. A second, thinner (5 m (16 ft)), medium-grained sandstone body near the top of the section shows evidence of channelization, with a Facies B bed pinching out laterally into interbedded shale and Facies E beds (fig. 20). This sandstone body is bounded at its base and top by interbedded shale and sandstone. The Facies A and B beds show Bouma Ta or Tab divisions, contain shale rip-up clasts, and commonly are concretionary.

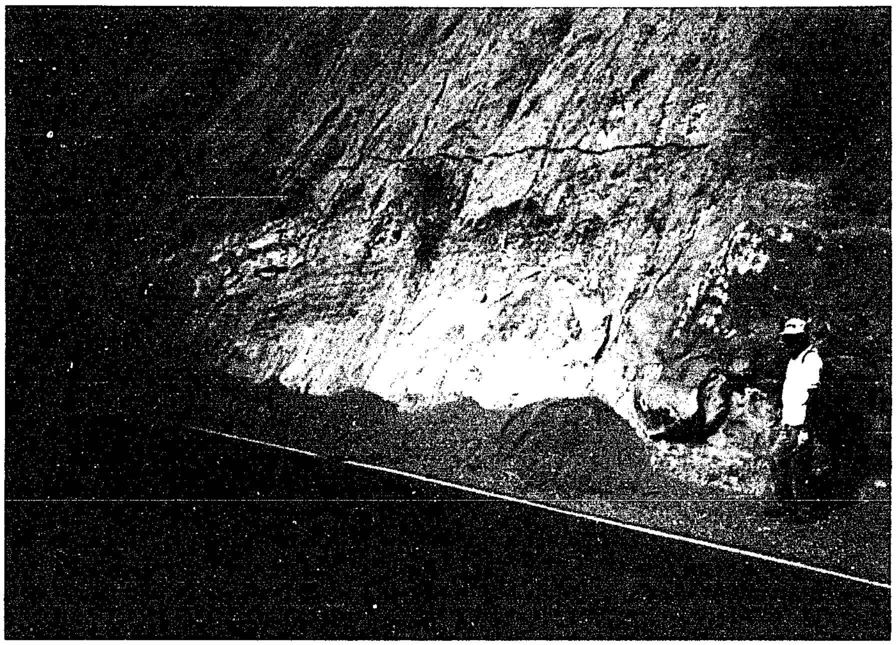


Figure 20. Facies B, D, and E sandstones of the Marsh Creek Formation near the top of the Marsh Creek measured section with Dr. Henry J. Moore II for scale (sec. 4, T.1S., R.2E., Antioch South 7.5-minute topographic quadrangle).

Fifty-five flute and groove casts and channel orientations on 22 different beds along and in the vicinity of the Marsh Creek measured section were employed as paleocurrent indicators. Flute casts consistently indicate a west to southwest transport direction; therefore, groove casts and channels that have a similar trend are inferred to represent a similar transport direction. The mean paleocurrent measurement is 237 degrees, with a range from 192 to 278 degrees (fig. 21)

Interpretations and Discussion

Based on (1) the total thickness of the sections, (2) overall distribution of sandstone, (3) distribution of facies and facies associations, (4) paleocurrent measurements, and (5) previous work, the Forbes Formation is interpreted to represent part of a southward-prograding, mud-rich, submarine fan-slope system; the Marsh Creek Formation is interpreted as a separate, west-southwest-prograding, mixed-sediment submarine-fan system.

The thickness pattern of the three F-zone sections most convincingly suggests the presence of two depositional systems. The thicknesses of the Putah Creek (T.8N., R.2W., 1604 m) and Gates Canyon (T.6N., R.2W., 1202 m) sections in the Coast Ranges north of Vacaville show a decrease in thickness of 402 m (1321 ft) to the south. Much farther to the south, in the northeastern Diablo Range, the Marsh

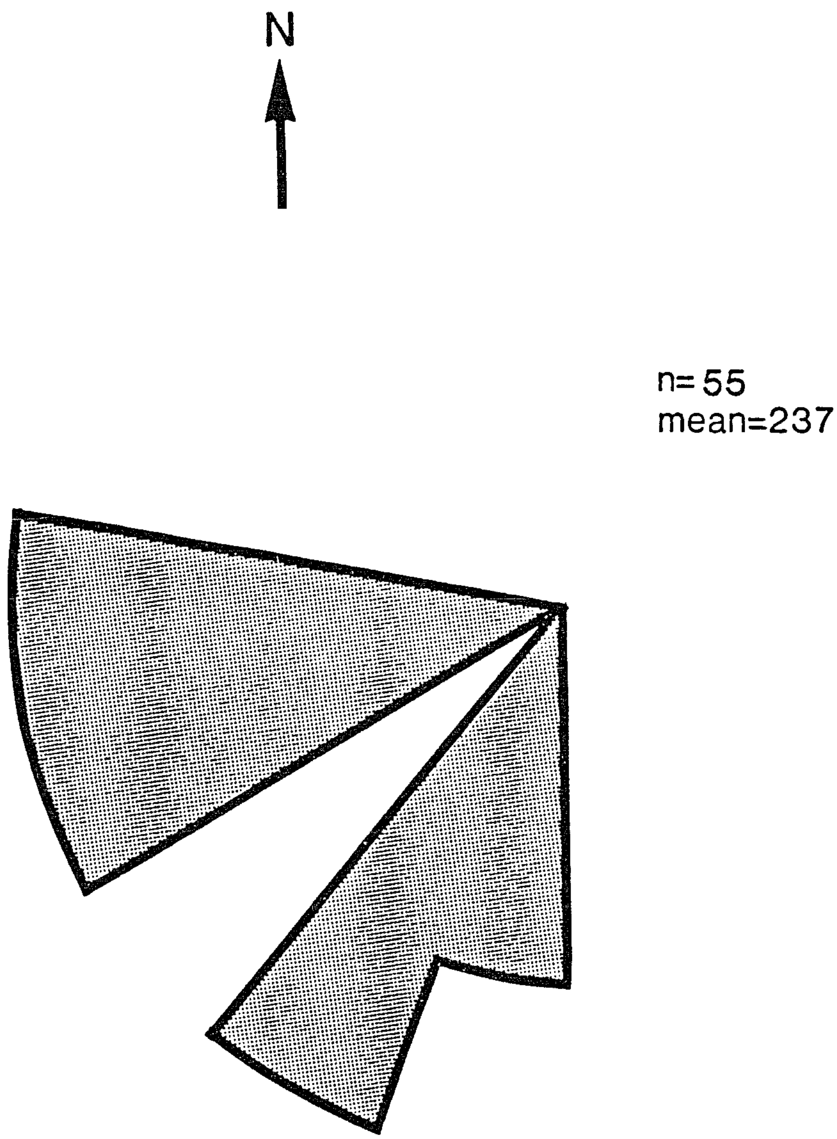


Figure 21. Paleocurrent rose diagram based on Marsh Creek data.

Creek (T.1N., R.1-2E., 1329 m) section shows an increase in thickness of 127 m (418 ft) relative to the southernmost section (Gates Canyon) in the Coast Ranges.

The distribution of sandstone within the two measured sections in the Coast Ranges is distinctly different from that in the northeastern Diablo Range. The Putah Creek and Gates Canyon sections show a significant decrease in sandstone relative to shale/covered interval in the upper parts of the sections. The lower 1010 m of the Putah Creek section has 18% sandstone and the upper 594 m has 5% sandstone. The lower 975 m of the Gates Canyon section has 12% sandstone and the upper 227 m has 3% sandstone. The lower parts of these sections with a high concentration of sandstone are interpreted as submarine-fan deposits, and the upper parts of the sections with a lower concentration of sandstone are interpreted to mark the change to slope deposits. The decrease in thickness between these two sections of 402 m (1321 ft) is reflected primarily in the slope deposits, which thin by 367 m (1204 ft). This is consistent with the biostratigraphic and subsurface data that suggest a southward-thinning Forbes system, primarily of the slope facies (plate 8).

The distribution of sandstone within the Marsh Creek section does not show any clear pattern. In contrast to the sections in the Coast Ranges, the Marsh Creek section has a higher concentration of sandstone in the upper half of the section (15%) than in the the lower half of the section (12%). Total percentages of sandstone for each section are: (1) Marsh Creek, 27%, (2) Putah Creek, 23%, and (3) Gates Canyon, 15%.

The sandstone facies in the Putah Creek and Gates Canyon sections are remarkably similar; the Marsh Creek section shows some similarities, but also significant differences. The Putah Creek and Gates Canyon sections are dominated by Facies B beds and associated Facies E beds throughout the section. Sandstone bodies show lateral discontinuity and many Facies B beds show significant channellization and lateral thickness variations. These sandstone bodies are interpreted as channel-levee sequences that include channel, channel-margin, and levee facies associations within the submarine fan. Channel and channel-margin deposits are sandstone rich, generally thin upward, and are comprised chiefly of thick-bedded Facies B beds. Levee deposits are more thinnly bedded with more Facies E beds, tend to thicken upward, and are more shale rich. Thick shale/covered intervals separating the sandstone bodies may represent an interchannel facies association. The sandstone bodies in the upper part of the sections, where there is a significant decrease in sandstone, are interpreted as gully facies associations within the shale-rich slope. Sandstone bodies in the upper part of the sections are similar to those in the lower part of the section with the exception of the Facies A shale rip-up-clast conglomerates. However, it is the lower percentage of sandstone in the upper part of the section that supports the gully facies association interpretation. The vertical sequence of beds in Putah Creek and Gates Canyon sections suggests a prograding, mud-rich submarine-fan/slope system.

The Marsh Creek section can be divided into three distinct sandstone intervals with different facies and facies associations. The lower interval grades upwards from a shale-rich sequence with minor interbedded sandstones into a sandstone-rich sequence. This sandstone-rich sequence is dominated by sandstone bodies composed of Facies C and D beds, and many sandstone bodies show a general thickening-upward pattern. This lower interval is interpreted as a basin plain, fan fringe, and outer-fan lobe sequence. Nine separate lobes have been distingished within the sandstone-rich sequence (Appendix 2).

The middle sandstone interval is very similar to the channel-levee sequences of the Putah Creek and Gates Canyon sections. This interval is dominated by Facies B beds that are channelized and vary in thickness laterally. Thinner Facies D and E beds commonly are interbedded with the Facies B beds within this interval. This interval is interpreted as a middle-fan, channel-levee sequence with channel, channel-margin, levee, and interchannel facies associations. The thick, covered interval separating the lower and middle intervals is interpreted as an outer-fan/middle-fan transition.

The upper interval is represented by coarse, thick-bedded, highly channelized Facies A and B beds with interbedded shale and Facies E beds. The sandstone packages show a general thinning-upward sequence and are separated by shale and covered intervals. This interval is interpreted as an inner-fan-channel sequence with sandstone-rich inner-fan channels separated by shale-rich interchannel deposits. The thick, covered section separating the middle and upper intervals probably represents a middle-fan/inner-fan transition. The entire vertical sequence of the Marsh Creek section suggests a prograding mixed-sediment submarine-fan system.

The paleocurrent measurements from the three sections show significant differences. The mean measurement from the Putah Creek section is 163 degrees, suggesting southward paleoflow with a slight eastward component. The mean from the Gates Canyon section is 180 degrees indicating a southward paleoflow. The Marsh Creek mean is 237 degrees, indicating paleoflow to the southwest. These Marsh Creek measurements are consistently to the west and southwest for the lower, middle, and upper intervals. This difference in paleocurrent direction between the Putah Creek and Gates Canyon areas and the Marsh Creek area again suggests the presence of two separate depositional systems.

PETROGRAPHY

Methods

The primary objective of the petrographic analysis is to determine any differences in modal compositions of F-zone sandstones in the Coast Ranges north of Vacaville and the northeastern Diablo Range. Twenty-seven sandstone samples were collected for petrographic analysis from Putah Creek, Gates Canyon, and the Cannon Hills in the Coast Ranges north of Vacaville (figs. 5-7) and from along Marsh Creek in the northeastern Diablo Range (fig. 8). Samples were collected throughout the measured sections to examine the possibility of changes in source through time. Additional samples were collected from the structurally complex Cannon Hills area, which contains the southernmost exposures of F-zone strata in the Coast Ranges. Wherever possible medium-grained sandstones were collected for consistency in modal analyses.

Samples were prepared by the National Petrographic Service in Houston, Texas for petrographic analysis. All samples were impregnated with blue epoxy dye, and half of each thin section was stained for potassium and plagioclase feldspar. Petrographic analysis was conducted with a Leitz petrographic microscope using a point-count stage. Point counting was done using the Gazzi-Dickinson method

(Dickinson, 1970; Ingersoll and others, 1984); more than 300 points were counted per sample. Counts were performed without knowledge of the sample localities to avoid bias. Petrographic parameters and definitions follow those of Dickinson (1970) and Ingersoll (1983), with some minor modifications.

Textural and Diagenetic Features

An understanding of the textural maturity and the diagenetic history of the sandstone samples was established prior to point counting to provide a framework to work within. Sandstones represent a similar level of textural maturity with the exception of two samples from Marsh Creek (MC-7 and MC-8), which are markedly different. The sandstones are poorly sorted and matrix-rich, and the grains are angular to subangular. These samples are texturally and compositionally immature to submature. The two anomalous samples from Marsh Creek are quartz-rich and moderately sorted, and have a high percentage of calcite cement; the grains are subrounded to rounded. These two samples show a much higher level of maturity both texturally and compositionally than all other samples.

Recognition of the diagenetic effects in the sandstone samples is extremely important to the petrographic analysis. The diagenetic alterations must be removed as much as possible to reconstruct the original detrital composition of the sandstone (Dickinson, 1970; Ingersoll, 1983). The principal diagenetic events that were recognized in this study are similar to those recognized by Mertz (1990) in his study of Campanian and Maestrichtian sandstones in the Sacramento basin.

The early diagenetic events include compaction and mineralogic alteration. Evidence of physical compaction includes breakage and deformation of individual grains and an overall tight packing. The development of a pseudomatrix that can significantly affect the modal data is common in many samples. Partial replacement of grains, especially plagioclase, by potassium feldspar, is common. Staining for both plagioclase and potassium feldspar greatly aids in the recognition of this process.

A second level of diagenetic events is mesogenesis or "intense diagenesis", which occurs above about 80 degrees C (Surdam and Crossey, 1987). The diagenetic events observed in this study attributable to mesogenesis include dissolution, precipitation of clay rims, and increasing development of pseudomatrix. Dissolution and partial dissolution of unstable aluminosilicate grains, mainly plagioclase, biotite, and volcanic lithic fragments, are widespread in some samples. This process creates abundant secondary porosity and can significantly affect modal data if not recognized. Precipitation of illite/smectite clay rims, significantly occluding pore space, also was observed. High levels of pseudomatrix development were recognized in some samples; reconstruction of the original detrital modes in these samples was especially difficult. A late-stage diagenetic event that was observed in the two anomalous Marsh Creek samples was the precipitation of calcite cement. In these samples, virtually all original pore space has been filled by cement.

Provenance

The objective of the petrographic study is to determine any modal differences of the F-zone sandstones in the Coast Ranges north of Vacaville and the northeastern Diablo Range. This should confirm or deny the presence of different Forbes and Marsh Creek systems and show if there was any mixing between these systems.

Study of the vertical sequence of the Great Valley Group documents the unroofing of the Sierran magmatic arc (Dickinson, 1970; Dickinson and Rich, 1972; Dickinson and others, 1979, 1983; Ingersoll, 1978, 1983; Dickinson and Suczek, 1979; Mansfield, 1979). The lithic parameters developed by these workers that are used in this study are defined in Table 2.

Ingersoll (1983) used seven petrographic parameters to define six units called petrofacies. The Campanian F-zone sandstones were included by Ingersoll in the Rumsey

Qm	=	Monocrystalline Quartz
Qp	=	Polycrystalline Quartz (including chert)
Q	=	Total Quartz (Qm + Qp)
P	=	Plagioclase feldspar
K	=	Potassium feldspar
F	=	Total feldspar (P + K)
Ls	=	Sedimentary lithic fragment
Lm	=	Metamorphic lithic fragment
Lv	=	Volcanic lithic fragment
L	=	Ls + Lm + Lv
Lt	=	L + Qp
M	=	Mica
Ms	=	Miscellaneous unidentified framework grains

Table 2. Explanation of petrographic parameters.

petrofacies, the youngest of the petrofacies units. QFL and QmFLt ternary diagrams study show that 25 of the 27 samples from this study fall within or very close to the Rumsey petrofacies (figs. 22 and 23; table 3). The two anomalous samples from the Marsh Creek section fall within the field of recycled orogenic detritus (Dickinson and others, 1983). QmPK and LvLsLm ternary diagrams and P/F, Lv/L, and Qp/Q ratios for samples from this study also are similar to those for the Rumsey petrofacies (figs 24-26).

Coast Ranges North of Vacaville

The eighteen samples (figs. 5-7; table 3) from the three localities in the Coast Ranges north of Vacaville (Putah Creek, Gates Canyon, and Cannon Hills) yielded very similar results and will be discussed together. On QFL and QmFLt ternary diagrams (figs. 22 and 23) these samples are grouped very closely and fall within the dissected arc field of Dickinson and others (1983). These samples correspond very closely with the Rumsey petrofacies, with about 90% falling within the limits of Ingersoll's (1983) Rumsey field. These samples, however, are slightly more feldspathic than those of the typical Rumsey petrofacies. The QmPK ternary diagram (fig. 24) shows less of a correspondence with the Rumsey petrofacies, with just over 60% of the samples falling within the Rumsey field. The samples that fall outside the Rumsey field have a

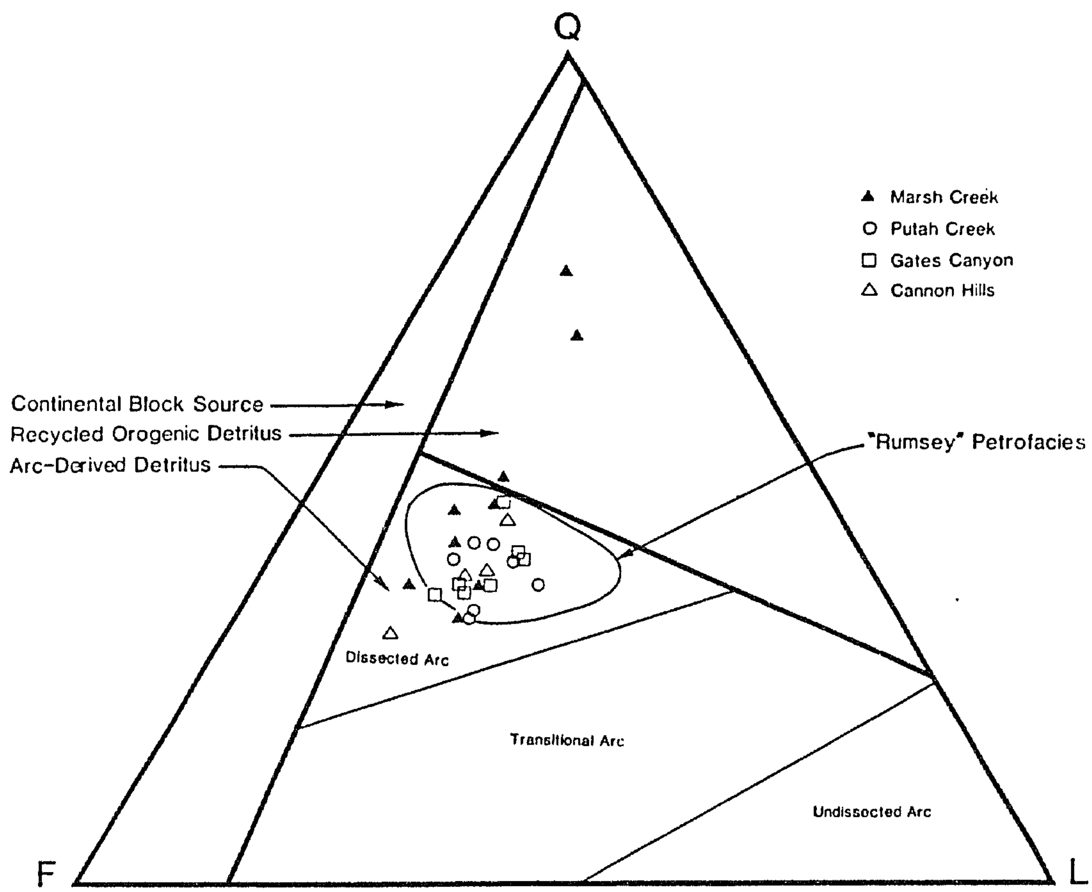


Figure 22. QFL ternary diagram for F-zone sandstones. Fields were defined by Dickinson and others (1983) and Ingersoll (1983).

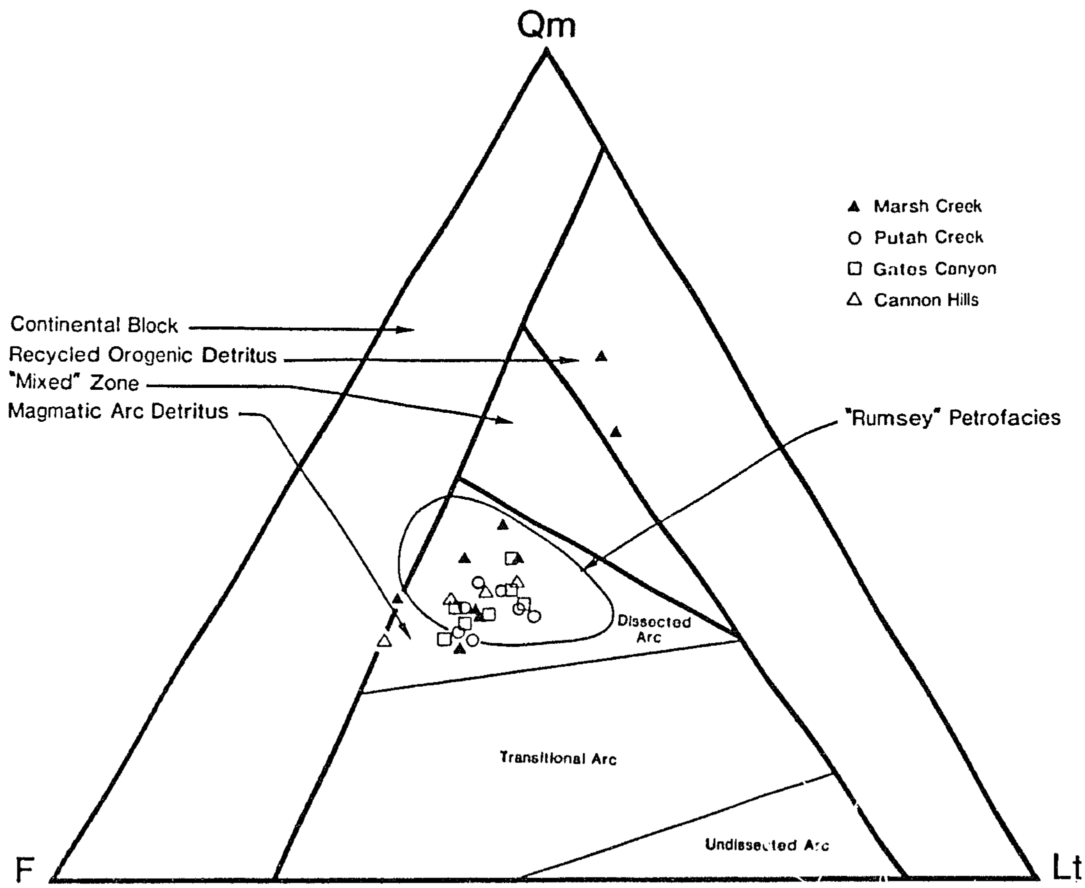


Figure 23. QmFLt ternary diagram for F-zone sandstones. Fields were defined by Dickinson and others (1983) and Ingersoll (1983).

	QFL%					FRMK%				QmPK%			LmLvLs%		
Sample No.	Q	Qm	F	L	Lt	M	P/F	Lv/L	Qp/Q	Qm	P	K	Lm	Lv	Ls
Putah Creek															
SS-1	41	36	39	20	25	8	61	60	12	48	32	20	34	60	6
SS-2	36	32	35	29	33	7	69	68	11	49	35	16	25	68	7
SS-3	39	33	36	25	31	5	60	68	15	48	31	21	25	68	7
SS-4	39	33	42	19	25	8	70	60	16	44	39	17	30	60	10
SS-5	33	29	43	24	28	5	62	70	13	40	37	23	16	70	14
SS-6	41	35	37	22	27	2	65	55	13	49	33	18	36	55	9
SS-7	32	30	44	24	26	6	59	73	6	41	35	24	22	73	5
Mean	37.3	32.6	39.4	23.3	27.9	5.9	63.7	64.9	12.3	45.6	34.6	19.9	26.9	64.9	8.3
S.D.	3.7	2.5	3.6	3.4	3.1	2.1	4.4	6.5	3.3	3.9	2.8	3.0	7.0	6.5	3.0
Gates Canyon															
SS-1	36	32	40	24	28	4	72	71	11	44	40	16	21	71	8
SS-2	39	35	36	25	29	5	59	73	10	49	30	21	24	73	3
SS-3	36	33	43	21	24	8	65	73	8	43	37	20	23	73	4
SS-4	46	39	34	20	27	5	68	52	16	53	32	15	39	52	9
SS-5	39	33	36	26	31	7	59	71	15	48	31	22	23	71	6
SS-6	35	31	43	22	26	6	58	69	12	42	34	24	29	69	2
SS-7	35	29	46	19	24	5	68	70	15	39	42	19	19	70	11
Mean	38.0	33.1	39.7	22.4	27.0	5.7	64.1	68.4	12.4	45.4	35.1	19.6	25.4	68.4	6.1
S.D.	3.9	3.2	4.5	2.6	2.6	1.4	3.9	7.4	3.0	4.8	4.6	3.2	6.7	7.4	3.3
Cannon Hills															
SS-1	38	35	39	23	26	6	56	66	8	47	30	23	20	66	14
SS-2	37	34	43	21	23	7	51	77	6	45	28	27	18	77	5
SS-3	30	29	52	17	19	8	65	49	5	35	42	23	45	49	6
SS-4	44	36	35	22	29	3	71	52	17	51	35	14	32	52	16
Mean	37.7	33.5	42.3	20.8	24.3	6.0	60.8	61.0	9.0	44.5	33.8	21.8	28.8	61.0	10.3
S.D.	5.7	3.1	7.3	2.6	4.3	3.7	9.0	13.0	5.5	6.8	6.2	5.5	12.5	13.0	5.6
Marsh Creek															
SS-1	45	39	39	16	22	5	73	52	13	50	37	13	34	52	14
SS-2	49	43	33	19	24	5	68	68	11	57	29	14	26	68	6
SS-3	32	28	45	23	27	9	67	66	13	38	42	20	27	66	7
SS-4	36	32	41	23	27	7	65	63	10	44	36	20	26	63	11
SS-5	46	39	34	20	26	6	67	67	14	54	31	16	18	67	15
SS-6	41	32	41	18	30	7	58	64	21	44	33	23	28	64	8
SS-7	74	63	13	13	24	0	37	55	14	83	6	11	35	55	10
SS-8	66	54	16	18	30	1	35	60	18	77	8	15	28	60	12
SS-9	36	34	48	16	18	6	55	64	6	41	32	27	33	64	3
Mean	47.2	40.4	34.4	18.4	25.3	5.1	58.3	62.1	13.3	54.2	28.2	17.7	28.3	62.1	9.6
S.D.	14.2	11.4	12.3	3.3	3.8	2.9	13.8	5.5	4.4	15.9	12.6	5.2	5.2	5.5	3.9

Table 3. Recalculated framework parameters from point-count data of F-zone sandstones (S.D. = Standard Deviation).

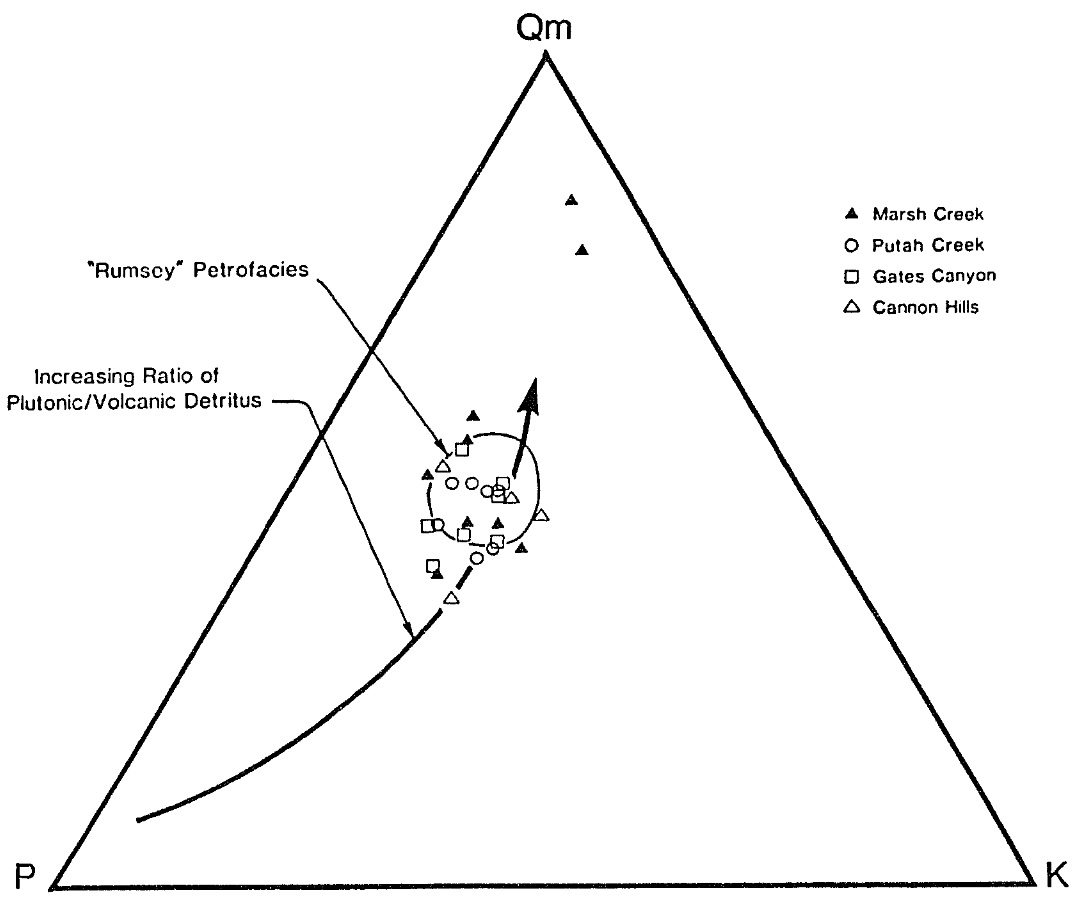


Figure 24. QmPK ternary diagram for F-zone sandstones. Arrow was defined by Dickinson and Suczek (1979) and "Rumsey" field by Ingersoll (1983).

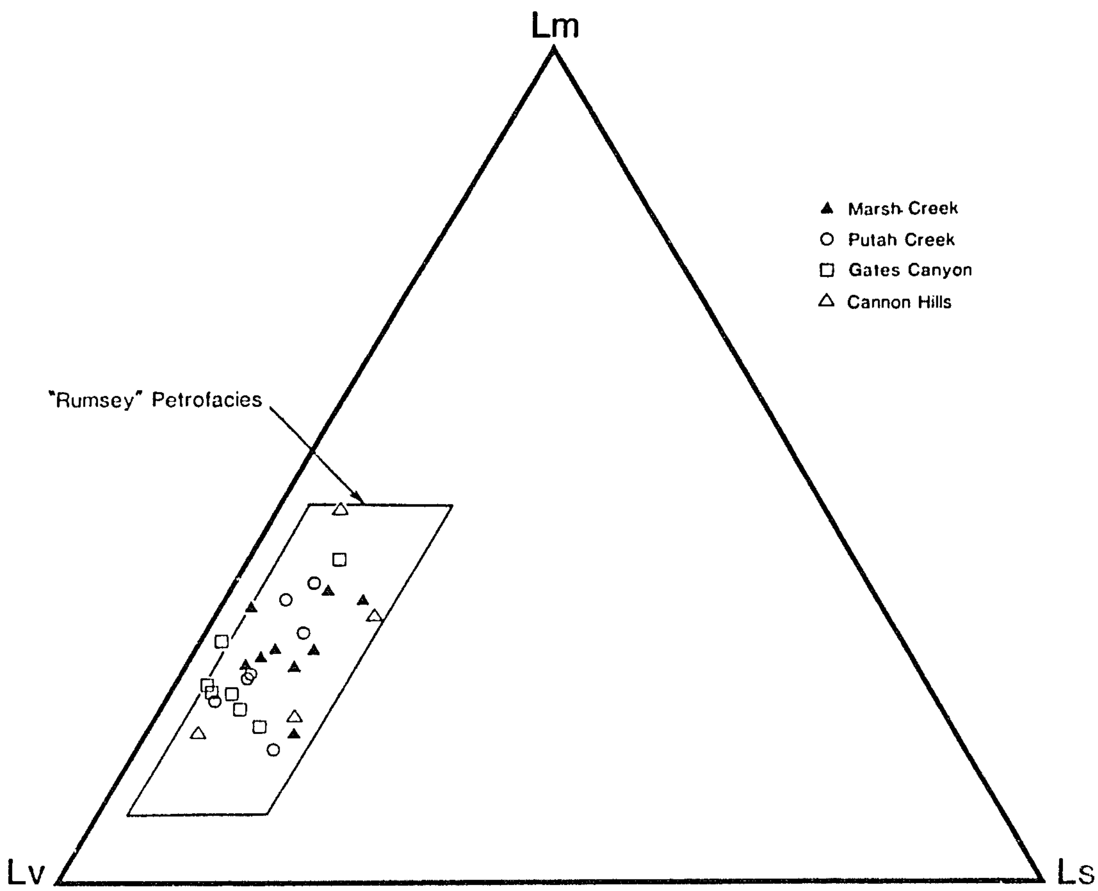


Figure 25. LvLsLm ternary diagram for F-zone sandstones. "Rumsey" field is from Ingersoll (1983).

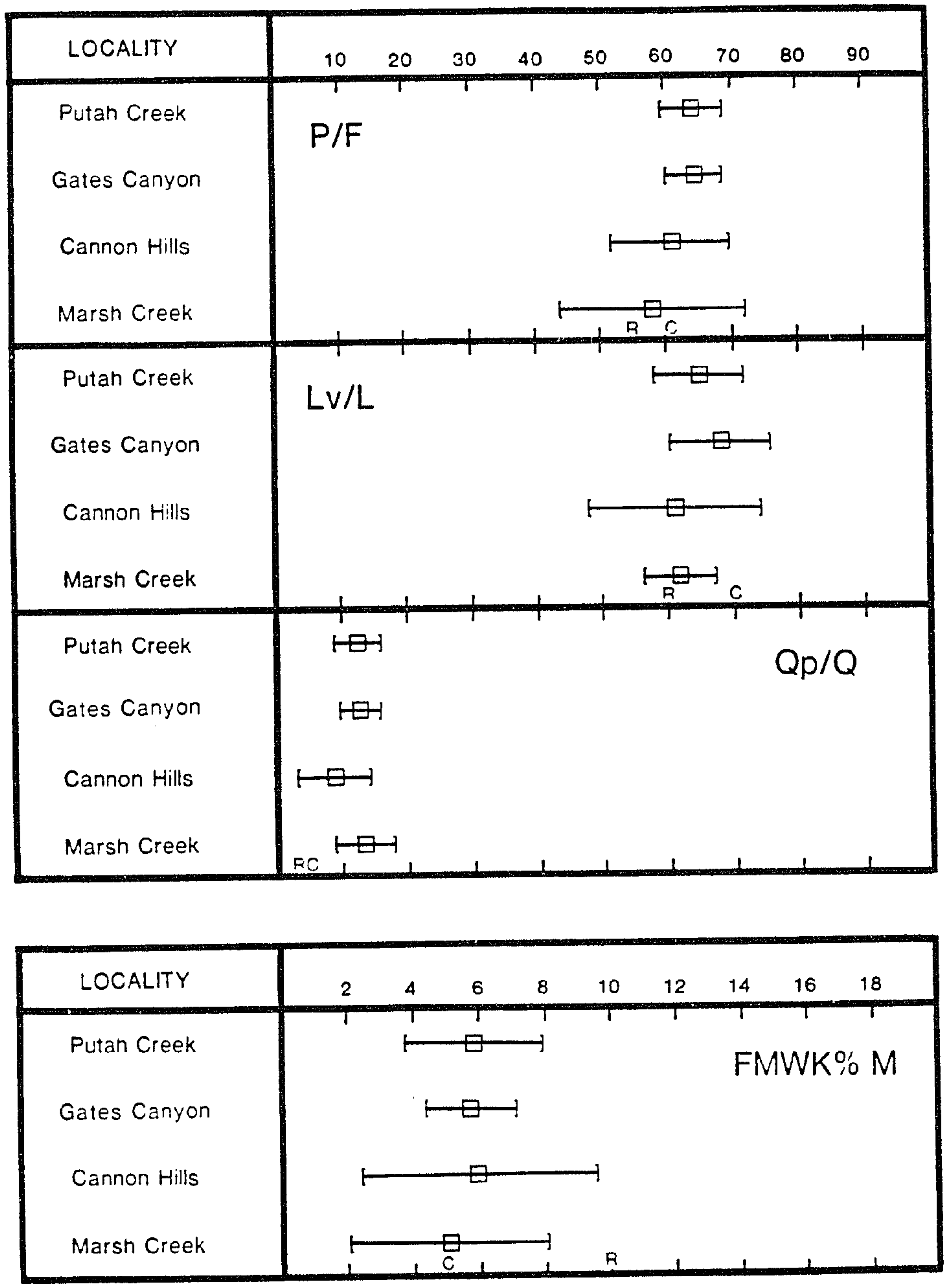


Figure 26. Ratios between selected lithologic framework components for F-zone sandstones. Squares represent the mean value and bar scales the standard deviation. See Table 3 for calculated values. Abbreviations: R = mean for Rumsey petrofacies; C = mean for Cortina petrofacies.

relatively large amount of plagioclase. On the LvLsLm ternary diagram, however, these samples fit very closely with Rumsey values (fig. 25).

P/F, Lv/L, and Qp/Q values and the percent framework mica were calculated along with standard deviations for these sandstones (fig. 26; table 3). The P/F ratio is the most important parameter for determining petrofacies (Ingersoll, 1983). Coast Range samples with means ranging from 61% to 64% indicate a slightly higher ratio of P/F than the typical Rumsey mean of 55%. These values show a closer relationship with the Cortina petrofacies, which is slightly older than the Rumsey petrofacies. The Lv/L ratios also are slightly higher than the Rumsey mean of 60%; values range from 61% to 68% for the three Coast Range localities. These values fall between the Rumsey and Cortina petrofacies means of Ingersoll (1983). The Qp/Q ratios which range from 9% to 12% are not in line with either the Rumsey or Cortina petrofacies; the Rumsey is 3% and Cortina is 5%. The closest match is to the older Boxer petrofacies (9%). The percent framework mica from the Coast Range samples collected for this study is just below 6%; this value is closer to the Cortina petrofacies (5%) than the Rumsey petrofacies (10%).

Northeastern Diablo Range

Nine samples from along Marsh Creek in the northeastern Diablo Range were evaluated (fig. 8; table 3). QFL and QmFLt ternary diagrams (figs. 22 and 23) show that seven of these samples fall within or very close to the dissected arc field of Dickinson and others (1983). Two samples, MC-7 and MC-8, fall within the recycled orogenic detritus field of Dickinson and others (1983), far from the grouping of the other samples. On the QFL ternary diagram fewer than half of the Marsh Creek samples fall within the Ingersoll's (1983) Rumsey petrofacies; some samples are more feldspathic, whereas others are more quartzose. The QmPK ternary diagram also shows the variability of these samples; only three samples fall within the Rumsey field (fig. 24). On the LvLsLm ternary diagram, the samples show a relatively close grouping, all within the Rumsey field (fig. 25).

The P/F ratio for the Marsh Creek samples (58%) falls between the Rumsey petrofacies mean (55%) and Cortina petrofacies mean (61%). The Lv/L ratio of these samples (62%) corresponds relatively closely to the Rumsey mean (60%). The Qp/Q ratio for these samples (13%), which is similar to the samples from the Coast Ranges north of Vacaville, is significantly higher than the Rumsey (3%), Cortina (5%), and Boxer (9%) petrofacies means. The percent framework mica for these samples is slightly more than 5%, which is very close to the Cortina petrofacies value of 5%. This average value, however, is somewhat affected by the lack of mica in the two quartz-rich samples, MC-7 and 8.

Discussion

F-zone sandstone samples from the Coast Ranges north of Vacaville and the northeastern Diablo Range generally fit into the petrographic models developed for the Great Valley Group (Dickinson and Suczek, 1979; Dickinson and others, 1983; Ingersoll, 1983). The majority of the 27 samples (figs. 22 and 23) fall within or very close to the dissected arc field of Dickinson and others (1983). The exceptions to this are the two quartz-rich samples from the upper portion of the Marsh Creek section that fall within the recycled orogenic detritus field. Most samples (figs. 22-25) also closely resemble the Rumsey petrofacies of Ingersoll (1983); however, some ratios of framework parameters fit the Cortina petrofacies better (fig. 26).

A detailed comparison of the samples from the Coast Ranges north of Vacaville and the northeastern Diablo Range reveals several distinct differences. The QFL, QmFLt, and QmPK ternary diagrams (figs. 22-24) show these differences most clearly. Samples from the three localities in the Coast Ranges north of Vacaville fall into a tight grouping, suggesting that they had a similar source and transport and diagenetic histories. In contrast, the samples from the northeastern Diablo Range show a much greater variation, suggesting that they had a more variable source and/or transport and diagenetic histories. Some samples from Marsh Creek fall into the tight grouping of samples from the Coast Ranges north of Vacaville, but it is difficult to establish a vertical pattern from the Marsh Creek samples that might suggest a mixing of the two systems.

SUMMARY OF KEY ELEMENTS

The primary objective of this study was to develop a paleogeographic reconstruction and depositional history for the late Santonian to middle Campanian strata in the southern Sacramento and northern San Joaquin basins. A combination of biostratigraphic, structural, subsurface stratigraphic, outcrop, and petrographic data was used to perform this study.

Biostratigraphic Correlations

The first objective was to establish chronostratigraphic boundaries for the late Santonian to middle Campanian strata within the study area. Foraminiferal and calcareous nannofossils provide the basis for the biostratigraphic correlations (Goudkoff, 1945; Miller, 1983; Almgren, 1986). The interval of interest is the thick F-zone (F-1 and F-2 zone) submarine-fan deposits bounded at the base by the Dobbins Shale and at the top by the Sacramento Shale.

The Dobbins Shale and Sacramento Shale apparently represent basinwide shales that were deposited during relative high sea-level stands. These units are both relatively thin, contain very distinct microfossil assemblages and represent good chronostratigraphic units (Almgren, 1986; Filewicz, 1986). Both the Dobbins Shale (representing the uppermost G-1 zone) and Sacramento Shale (representing the Lower E zone) have been biostratigraphically correlated from Putah Creek to the Cannon Hills in the Coast Ranges north of Vacaville, along Marsh Creek in the northeastern Diablo Range, and in the subsurface of the southern Sacramento and northern San Joaquin basins. Thus, the correlation of these units provides the chronostratigraphic boundaries that define the F-zone-age submarine-fan deposits (fig. 27).

Basement Structure

The structure of the basement surface played a significant factor in controlling deposition of the lower Campanian F-zone strata. The structure-contour map (plate 2) shows four faults or fault complexes that trend northeast-southwest, perpendicular to strike of the basin, that are shown to offset the basement surface. These are: (1) the Freeport fault, (2) the Thornton fault, (3) the Stockton fault complex, and (4) the Modesto fault. The timing of this faulting was Campanian and/or pre-Campanian, based on the isopach thickness of F-zone strata in the vicinity of the faults (plate 4).

The Stockton fault complex and the Modesto fault are especially important because the downthrown basement block between these two faults created a large subbasin, the Stockton subbasin, that was filled with a significant

Figure 27. Stratigraphic nomenclature, biostratigraphic zonation, and submarine-fan facies associations for late Santonian to middle Campanian strata.

EUROPEAN STAGES	BENTHIC FORAMINIFERAL ZONES Goudkoff (1945) Almgren (1986)	COAST RANGES NORTH OF VACAVILLE		NORTHEASTERN DIABLO RANGE	
Middle Campanian	Lower E	Sacramento Shale		Sacramento Shale	
Early Campanian	F–1	Forbes Formation	Slope	Marsh Creek Formation	Inner Fan
	F–2		Submarine Fan		Middle Fan
					Outer Fan
Late Santonian	G–1	Dobbins Shale		Dobbins Shale	

thickness of F-zone deposits (plate 4). The basement structure-contour map indicates about 2000 ft (610 m) of down-to-the-south offset on the main Stockton fault.

Consideration of the present nature of the Stockton fault and the subsurface stratigraphic relationships suggests that there may have been about 4000 ft (1220 m) of offset during the Late Cretaceous phase of movement. This is based on the well-documented late Paleocene phase of movement that demonstrates about 2000 ft of reverse displacement, down-to-the-north on the Stockton fault (Callaway, 1964; Teitsworth, 1968). This is the opposite sense of offset from the Late Cretaceous phase of movement which compensated for only about 2000 ft (610 m) of offset in the basement. Regional stratigraphic cross section E-E′ (plate 9) also shows 4000 ft (1220 m) of Campanian strata (F and E zones) just south of the Stockton fault, suggesting down-to-the-south offset on the fault.

Stratigraphy and Depositional Model

Work on the subsurface stratigraphy, outcrop stratigraphy, and sedimentology resulted in data allowing a much greater understanding of the lower Campanian F-zone strata than had been possible earlier. The isopach maps (plates 3 and 4) and stratigraphic cross sections (plates 5-9), based on well-log correlations (Appendix 1), illustrate the subsurface stratigraphic relationships in the southern Sacramento and northern San Joaquin basins. The three detailed measured sections with facies and facies associations (Appendix 2) and paleocurrent measurements have allowed the development of submarine-fan models.

Subsurface Stratigraphy

Well-log correlations support the biostratigraphic data, which suggest that the F-zone rocks are bounded by the basinwide subjacent Dobbins Shale and superjacent Sacramento Shale (fig. 27). These units are readily correlated based on their low-resistivity log signature.

The isopach map of rocks of the F zone (plate 4) indicates two distinct thick trends, further suggesting the presence of two separate submarine-fan systems. The rocks of the thick trend in the northern portion of the study area (T.9-12N., R.1W.) belong to the Forbes Formation, a southward-prograding submarine-fan system. The southward thinning of this system is closely related to the southward termination of the Kione Formation (plates 3 and 8), the time-equivalent delta that fed the Forbes system.

A second thick trend of F-zone rock exists within the Stockton subbasin (plate 4). This structurally controlled subbasin was the depocenter for the Marsh Creek Formation, which was derived from the Sierra Nevada to the east. Well-logs along the eastern margin of the subbasin display thick sandstones interpreted as east-west-trending submarine canyon systems that transported sediment westward into the basin (plates 7 and 9).

Outcrop Stratigraphy and Sedimentology

Three detailed outcrop measured sections of complete F-zone intervals provided information to interpret submarine-fan models based on facies and facies associations (Appendix 2). The total thicknesses of the sections helped to establish F-zone isopach trends (plate 4). Paleocurrent indicators also were measured along each measured section to determine paleoflow.

The two measured sections in the Coast Ranges north of Vacaville, at Putah Creek and Gates Canyon (figs. 5 and 6), exhibit very similar stratigraphic and sedimentologic characteristics. Sandstone bodies throughout the sections are lenticular and dominated by Facies B beds. They verify that this system is made up of meandering channel-levee complexes that form part of a mud-rich submarine-fan system. Significant decreases in sandstone in the upper portion of each section reflect a slope facies overlying the submarine-fan deposits.

The total thickness from Putah Creek section to the Gates Canyon section decreases by 402 m (1321 ft). This thinning to the south corresponds with the subsurface isopach trends which also show southward thinning. Sandstone to shale/covered interval ratios calculated from the measured sections suggest that the thinning takes place principally in the slope deposits. This also suggests that the southward thinning is due to pinch out of the slope deposits. Paleocurrent measurements from Putah Creek and Gates Canyon both indicate a southerly paleoflow with a slight eastward component.

The measured sections of F-zone rocks at Putah Creek and Gates Canyon both represent the Forbes Formation. This unit was deposited in a southward-prograding mud-rich submarine-fan/slope system composed mainly of meadering channel-levee complexes (fig. 27).

The F-zone section measured at Marsh Creek in the northeastern Diablo Range is distinctly different from the two Coast Ranges sections. This section can be divided into lower, middle, and upper sandstone intervals, each exhibiting different facies and facies associations. This section is interpreted to be composed of outer-fan lobes, middle-fan channels, and inner-fan channels of a mixed-sediment submarine-fan system (fig. 27).

The significant increase in thickness of F-zone deposits in the northeastern Diablo Range indicates the presence of a different submarine-fan system. Paleocurrent indicators from the Marsh Creek section also confirm this; measurements indicate a westerly to southwesterly paleoflow.

The F-zone measured section from Marsh Creek in the northeastern Diablo Range represents the Marsh Creek Formation. This unit was a west- and southwest-prograding mixed-sediment submarine-fan system that was deposited transverse to the Great Valley basin axis. The deposition of this unit initially was limited to the Stockton subbasin, but subsequently it prograded out across the basin floor.

Provenance

F-zone sandstone samples collected for this study from four localities plot in the dissected arc field of Dickinson and others (1983), with the exception of two samples from Marsh Creek, which fall in the recycled orogenic field. Overall, the sandstones that fall within the dissected arc field also fit very closely with the Rumsey petrofacies of Ingersoll (1983). Some framework parameters plot closer to the Cortina petrofacies of Ingersoll (1983), but it is clear that they generally fit into the petrologic models previously established for the Great Valley Group.

Samples from the Coast Ranges north of Vacaville and the northeastern Diablo Range have some distinct differences recognizable on the QFL, QmFLt, and QmPK ternary diagrams (figs. 22-24). All 18 samples from the Forbes Formation in the Coast Ranges north of Vacaville fall into a very tight grouping (fig. 28), probably the result of an extensive transport history through the Kione delta system from the northern Sierra Nevada batholith or possibly the Idaho batholith (Mertz, 1990). Nine samples from Marsh Creek in the northeastern Diablo Range show a wide grouping (fig. 28). Some fall within or near the tight grouping of samples from the Coast Ranges north of Vacaville. This could suggest a possible mixing of two sources, but this appears to be unlikely because no vertical petrographic pattern has been recognized (table 3) and stratigraphic and sedimentologic evidence does not support mixing. The variability of the Marsh Creek samples probably reflects some sediment contributions from previously deposited shelf sandstones or the Sierran foothill metamorphic belt in addition to the batholithic source.

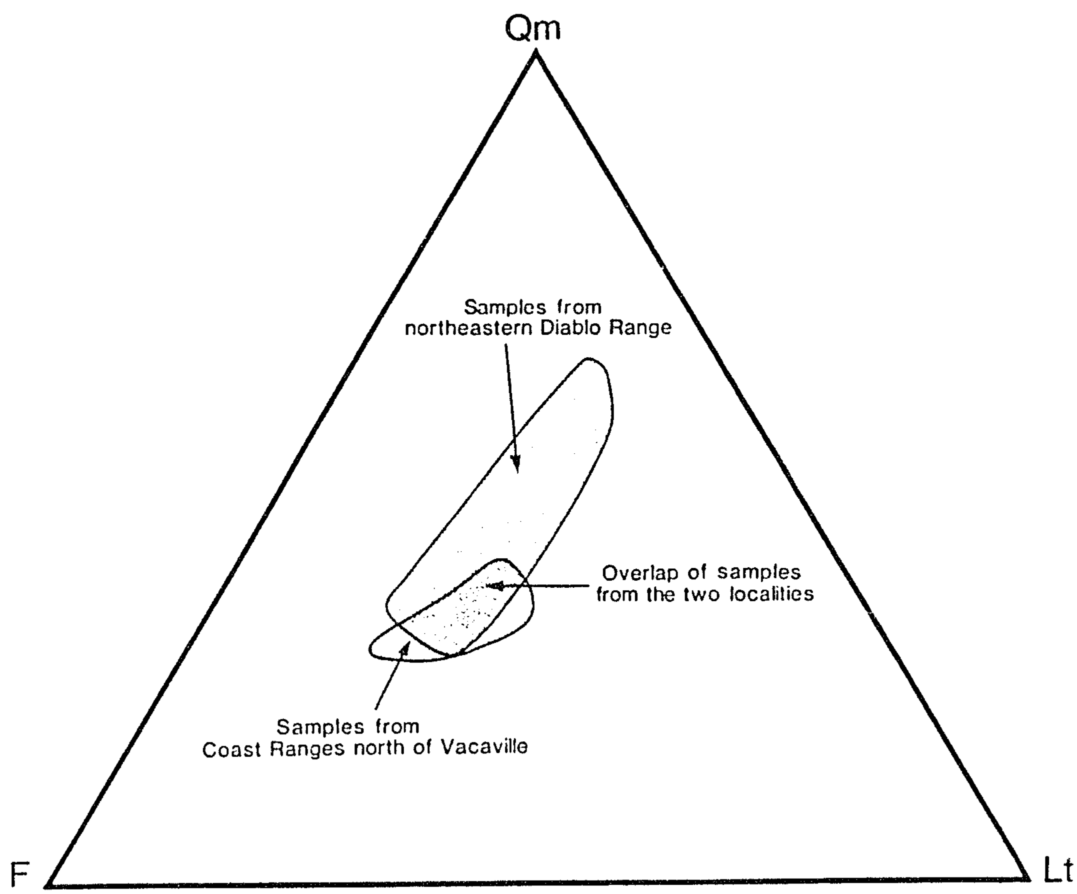


Figure 28. QmFLt ternary diagram for F-zone sandstone samples from the Coast Ranges north of Vacaville and the northeastern Diablo Range.

CONCLUSIONS

Thick lower Campanian F-zone submarine-fan deposits occur throughout the Sacramento and northern San Joaquin basins. Biostratigraphic data show that the submarine-fan deposits are between two basinwide shale units, the Dobbins Shale and Sacramento Shale, that can be used as chronostratigraphic boundaries. Thus, the major rock units between these shales can be considered coeval.

This study has documented the presence of two separate lower Campanian submarine-fan/slope systems in the southern Sacramento and northern San Joaquin basins. The Forbes system prograded southward down the plunging axis of the forearc basin (fig. 29). This was a mud-rich fan system composed principally of meandering channel-levee complexes. The Marsh Creek submarine-fan/slope system prograded westward and southwestward, transverse to the basin axis (fig. 29). This was a mixed-sediment fan system, consisting of outer-fan lobes, middle-fan channels, and inner-fan channels.

The factors that controlled the deposition of these units within the Great Valley forearc basin were responsible for producing their different features. The Forbes system was fed by an extensive delta system and prograded unrestricted down the entire length of the Sacramento basin. Transport through the delta system

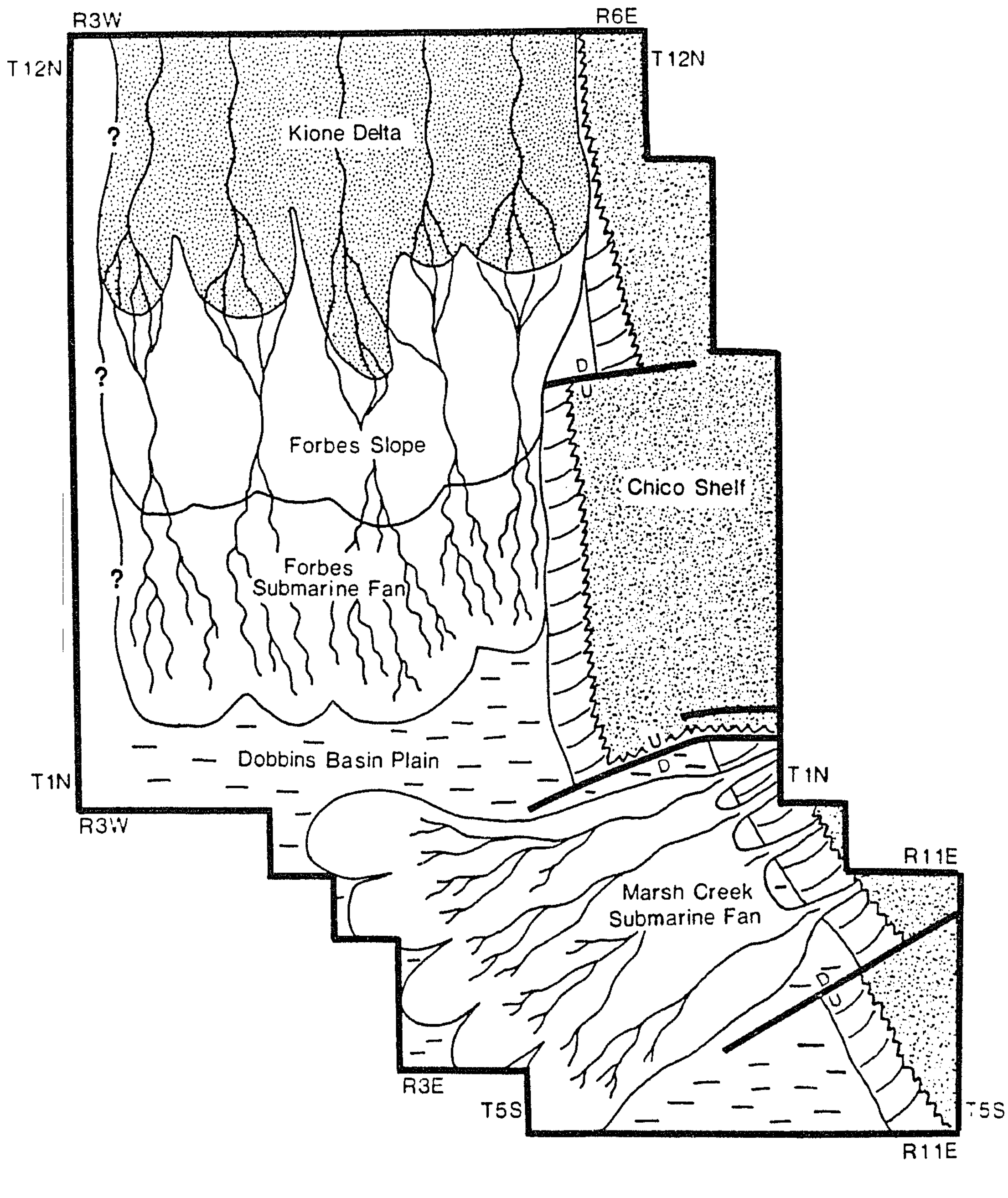


Figure 29. Early Campanian paleogeographic reconstruction.

has contributed to the relatively well-sorted nature of the Forbes sandstones. The unrestricted depositional basin allowed the Forbes to build southward until the Kione delta system shut down.

The Marsh Creek system was fed by large submarine-canyon systems, and deposition initially was limited to the Stockton subbasin. The petrographic variations and poor sorting of the Marsh Creek sandstones are a result of the relatively short transport history of the sediment and the variability of rock types in the source area. These factors led to the mixed-sediment nature of the Marsh Creek system. The extent and direction of progradation of the Marsh Creek system was controlled by Cretaceous fault systems.

This study shows that two separate submarine-fan systems, with contrasting depositional facies, transport directions, source areas, and structural controls, can form coevally within the same forearc basin setting.

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APPENDIX 1

WELL-LOG DATA

EXPLANATION FOR WELL-LOG CORRELATION DATABASE

Well Information

ID:	Represents well identification number used for this study. Well locations with ID numbers are found on the base map (plate 1).
Well Name:	Well name and number as it appears of the original well log.
Location:	Location of well in section, township, and range of the Mount Diablo Base Meridian.

Well-Log Correlations

Top K:	Top of the Cretaceous strata.
Ks:	Top of the Sacramento Shale.
Kk:	Top of the Kione Formation.
F zone:	Top of the F zone strata except where the Kione Formation is present (there the F zone log correlation represents the top of the Forbes Formation although the Kione Formation is in the F zone).
Kd:	Top of the Dobbins Shale.
bsmnt:	Top of the basement complex.

Well-Log Correlation Values

Numerical values represent the measured depth of the well-log correlation recorded from the original well log measured from the well head elevation.

ND:	No data for correlation.
NP:	Not present, horizon is not present depositionally or has been truncated by an unconformity.
NDE:	Not deep enough, horizon is below logged interval.
NSE:	Not shallow enough, horizon is above logged interval.

ID	WELL NAME		LOCATION	Top K	Ks	Kk	F zone	Kd	bsmnt
1	SCHOFIELD	#1-1	1-12N- 2W	2740	NP	NP	2740	NDE	NDE
2	PHILLIPS-LADD-ET AL	#26-2	2-12N- 2W	2655	NP	NP	2655	8790	NDE
3	GULF-NGC-PAYNE	#1	4-12N- 2W	2560	NP	NP	2560	7860	NDE
4	WEST DUNNIGAN	#1-13	13-12N- 2W	2450	NP	2450	2720	NDE	NDE
5	TIPPETS, MARY A.	#2	21-12N- 2W	1715	NP	NP	1715	NDE	NDE
6	WEST DUNNIGAN	#25-1	25-12N- 2W	1950	NP	1950	2290	NDE	NDE
7	HAMBLET	#1	36-12N- 2W	2050	NP	NP	2050	NDE	NDE
8	MUMMA	#1	1-12N- 1W	3690	4360	4710	5180	NDE	NDE
9	HERSHEY	#1	10-12N- 1W	4100	4100	4460	4955	NDE	NDE
10	ABELE	#1	29-12N- 1W	2260	2260	2530	2875	NDE	NDE
11	COOK, J.E., ET AL	#1	31-12N- 1W	1790	1790	1900	2290	8530	NDE
12	RIVER FARMS	#1	3-12N- 1E	ND	4580	4880	5060	9930	NDE
13	CAMERON RECLAMATION	#1	21-12N- 1E	ND	4970	5315	5500	NDE	NDE
14	RIVER FARMS	#4-1	23-12N- 1E	ND	4835	5235	5615	10795	NDE
15	HONIG	#1	1-12N- 2E	ND	3490	3910	4005	NDE	NDE
16	UNIT	#1-1	3-12N- 2E	ND	3910	4200	4465	8055	NDE
17	NELSON	#1-6	6-12N- 2E	ND	4240	4675	4950	9670	NDE
18	MEZGER	#1	10-12N- 2E	ND	3935	4405	4840	NDE	NDE
19	HONIG, BARBARA	#1	11-12N- 2E	ND	3730	4200	4460	8390	NDE
20	CHINA BEND	#1-1	20-12N- 2E	ND	4555	4990	5310	10295	NDE
21	ROBBINS	#A-1	21-12N- 2E	ND	4375	4840	5180	NDE	NDE
22	MAGOON ESTATE	#1	5-12N- 3E	ND	2990	3445	3690	7000	7630
23	KREIG	#12-15	12-12N- 3E	ND	2390	2930	3310	6040	6620
24	INGRAHAM	#1	13-12N- 3E	1750	2425	3020	3400	6115	NDE
25	SMC-CAMERON-DOUGHER	#1	31-12N- 3E	ND	3850	4350	4540	8410	8938
26	AILEEN, MARTY	#1	35-12N- 3E	ND	3115	3680	3980	NDE	NDE
27	CORLISS	#1	1-12N- 4E	2015	NP	NP	2015	3120	3448
28	DAVIS, TOM	#1	21-12N- 4E	2495	NP	2495	2540	4820	5250
29	VAN DYKE	#1	24-12N- 4E	2210	NP	NP	2210	3640	4100
30	LIENERT	#55-29	29-12N- 4E	2300	2430	2770	3100	5325	6023
31	OSTERLI	#3	31-12N- 4E	3050	3050	3165	3390	5935	6712
32	BONNEFELD	#1	10-12N- 5E	610	NP	NP	610	1505	1624
33	KINGSBURY	#4X-11	11-11N- 3W	500	NP	NP	500	555	NDE
34	BEMMERLY, L.M.	#1	8-11N- 1W	2200	2310	2520	2890	NDE	NDE
35	HERMLE	#1	22-11N- 1W	ND	3110	3330	3585	NDE	NDE
36	CARLETON & CO.	#1	25-11N- 1W	ND	4000	4200	4510	NDE	NDE
37	ARCO	#1	34-11N- 1W	ND	3660	3840	4140	NDE	NDE
38	UNIVERSAL-RICHEY	#1	35-11N- 1W	ND	3955	4165	4490	NDE	NDE
39	RICHIE	#1	36-11N- 1W	ND	4100	4300	4690	NDE	NDE
40	KNAGG-WALLACE	#1	12-11N- 1E	ND	5220	5580	5930	NDE	NDE
41	REIFF	#1	29-11N- 1E	3605	5180	5560	5635	11560	15180
42	SLAVEN	#1	30-11N- 1E	ND	4405	4620	4920	NDE	NDE
43	RIVER GARDEN FARMS	#1	4-11N- 2E	ND	4860	5245	5450	NDE	NDE
44	KCL-STANDARD-CAMER.	#1	32-11N- 2E	ND	5650	5950	6190	NDE	NDE
45	RITCHER	#1	5-11N- 3E	ND	3850	4385	4795	8140	NDE
46	AMERICAN	#1-1	12-11N- 3E	3100	3210	3540	3820	6880	NDE
47	DUERIG-KNAGGS-CHUR.	#1	34-11N- 3E	ND	4480	4825	5110	8280	NDE

ID	WELL NAME		LOCATION	Top K	Ks	Kk	F zone	Kd	bsmnt
48	SILLS	#1-3	3-11N- 4E	2650	NP	2650	2730	4920	NDE
49	OSTERLI	#2	5-11N- 4E	2480	2690	2920	3190	5550	6348
50	MORRISON	#1-9	9-11N- 4E	2615	2785	2980	3130	5665	NDE
51	LAUPPE	#1-28	28-11N- 4E	2950	3100	3310	3550	6050	NDE
52	DIAMOND K RANCH	#1	16-11N- 5E	ND	1290	1650	1970	3070	3364
53	DUNCAN	#1	9-10N- 2W	NSE	NSE	NSE	NSE	3390	NDE
54	ESPARTO CORE HOLE	#2	16-10N- 2W	NSE	NSE	NSE	NSE	3190	NDE
55	ESPARTO COREHOLE	#1	22-10N- 2W	800	NP	NP	800	4480	NDE
56	RUSA-LEDERER	#1	2-10N- 1W	ND	4100	4280	4665	NDE	NDE
57	ROCO-MAULER	#62-3	3-10N- 1W	ND	3940	4140	4550	NDE	NDE
58	STEVENS, ANNA B.	#1	7-10N- 1W	3150	3150	3370	3445	NDE	NDE
59	REIFF	#1	14-10N- 1W	ND	4555	4720	5070	NDE	NDE
60	STANDARD-HAYES	#44-24	24-10N- 1W	ND	4900	5030	5445	NDE	NDE
61	HORGAN COMMUNITY	#1	5-10N- 1E	ND	4775	4750	4800	NDE	NDE
62	SECTION 10	#1	10-10N- 1E	ND	5520	5720	5830	NDE	NDE
63	SHELL-OLIVER	#1	24-10N- 1E	ND	6000	6165	6330	NDE	NDE
64	PAYNE, E.A.	#1-11	11-10N- 2E	ND	5610	5890	5980	10770	NDE
65	SSJDD	#1	4-10N- 3E	ND	4730	4960	5270	9120	NDE
66	SILLS	#1-10	10-10N- 4E	ND	3685	3810	3960	7010	7818
67	RAYMOND	#1	14-10N- 4E	ND	3560	3690	4140	6655	NDE
68	HUMBLE-HICOK	#1	32-10N- 4E	3760	4640	4825	4920	8400	NDE
69	MUSCHETTO	#1	22-10N- 6E	1200	NP	NP	1200	1395	1680
70	ROMINGER, E.A.	#1	36- 9N- 2W	750	NP	NP	750	ND	ND
71	DESERET FARMS	#6-2	6- 9N- 1W	3370	3405	3670	3810	NDE	NDE
72	NEAVES-CHAPMAN	#1	31- 9N- 1W	1530	1580	NP	1835	NDE	NDE
73	ROCO-ULRICH	#77-6	6- 9N- 1E	ND	5340	5590	5850	NDE	NDE
74	CACHE CREEK RANCH	#1	8- 9N- 1E	3350	5520	5875	6050	ND	ND
75	INVESTMENT OPER.	#3-13	13- 9N- 2E	ND	6760	NP	6965	NDE	NDE
76	AGIP-WOODLAND SO.	#3-1	21- 9N- 2E	ND	7160	7265	7420	NDE	NDE
77	SWANSTON	#1	26- 9N- 3E	ND	6200	NP	6555	10990	NDE
78	MARTY	#1	18- 9N- 4E	ND	5295	NP	5535	9145	NDE
79	NATOMAS LAND CO.	#1	13- 9N- 6E	ND	ND	ND	ND	ND	1780
80	PEREZ	#1	32- 8N- 1W	3900	5165	NP	5415	NDE	NDE
81	CAMERON GLIDE	#1	14- 8N- 1E	ND	7650	NDE	NDE	NDE	NDE
82	WINTERS	#2-1	18- 8N- 1E	ND	6885	NP	7150	NDE	NDE
83	BELTRAMI	#4	25- 8N- 2E	ND	8665	NP	8890	NDE	NDE
84	CITIES-GLIDE-COLBY	#1	14- 8N- 3E	ND	7315	NP	7740	NDE	NDE
85	CURREY	#7	24- 7N- 2E	4490	9700	NP	10050	NDE	NDE
86	GLIDE	#4-1	1- 7N- 3E	5480	8530	NP	8780	11420	NDE
87	MAXWELL, JOHN C.	#1	7- 7N- 3E	4120	9010	9395	9460	NDE	NDE
88	GLIDE-COURT	#65-10	10- 7N- 3E	4300	8535	NP	8950	12410	15080
89	PARSONS	#1-1	24- 7N- 3E	4610	8885	NP	9170	NDE	NDE
90	MURDOCH	#1	27- 7N- 4E	3210	8035	NP	8510	10015	11610
91	UNION-DOW-STD COMM.	#1-1	31- 7N- 4E	3705	9040	NP	9330	11760	NDE
92	SHERMAN	#5	32- 7N- 4E	3590	8860	NP	9135	11320	NDE
93	ELLIOTT RANCH	#36-67	36- 7N- 4E	3700	7600	NP	7915	8495	NDE
94	UNION-DOW-ATTORNEY	#1	13- 7N- 5E	2850	4575	NP	4785	4960	5130
95	SACRAMENTO	#A-1	16- 7N- 5E	3220	6500	NP	6720	7100	7660

ID	WELL NAME		LOCATION	Top K	Ks	Kk	F zone	Kd	bsmnt
96	HBC-EDWARDS, E A	#1-17	17- 7N- 5E	2950	6770	NP	7365	8155	NDE
97	SIMS COMMUNITY	#2	18- 7N- 5E	2665	6720	NP	7150	7865	9400
98	SIMMS, ET AL	#1	20- 7N- 5E	ND	6970	NP	7270	7780	8275
99	KRAMER, J.P.	#1	26- 7N- 5E	3285	5490	NP	5765	6080	6420
100	CRYSTAL 28	#1	28- 7N- 5E	3540	6575	NP	6880	7320	NDE
101	OCCIDENTAL-FREEPORT	#B-1	29- 7N- 5E	ND	6635	NP	7020	7330	8100
102	BERRY	#1	31- 7N- 5E	3665	7365	NP	7560	8110	8640
103	ELLIOTT RANCH	#32-36	32- 7N- 5E	ND	7215	NP	7365	7820	NDE
104	CAL. PLANS-POPPY	#3	33- 7N- 5E	3575	6810	NP	7090	7400	NDE
105	VENADA-PEDERSON	#1	34- 7N- 5E	3310	5740	NP	5815	6330	6830
106	H & C-HARLANDER	#1	4- 7N- 6E	ND	2670	NP	3080	3930	5080
107	PLAN	#1	8- 7N- 6E	1550	3190	NP	3410	3690	NDE
108	PLAN	#1	19- 7N- 6E	2745	4290	NP	4450	4610	4780
109	WAEGELL	#1	6- 7N- 7E	ND	2590	NP	2640	2810	3000
110	BOTTIMORE, C.W.	#2	34- 7N- 7E	ND	2425	NP	2455	NP	2590
111	MCCULLOCH-MASON	#1	32- 6N- 1W	1715	NP	NP	1715	4795	NDE
112	VENADA-LAUREL, E A	#1	3- 6N- 3E	5550	9550	NP	9790	NDE	NDE
113	POLLOCK	#1	5- 6N- 4E	ND	9015	NP	9325	11550	NDE
114	WURSTER	#3	27- 6N- 4E	4085	9490	NP	9755	11670	NDE
115	GOLD	#1	3- 6N- 5E	ND	6580	NP	7025	7255	7780
116	CAL. PLANS-POPPY	#2	4- 6N- 5E	ND	6650	NP	6955	7320	NDE
117	VITA-FEE	#11-5	5- 6N- 5E	ND	7380	NP	7510	8015	NDE
118	NGC-ELLIOT	#6-45	6- 6N- 5E	3715	7840	NP	8095	8735	NDE
119	JILLSON	#1	9- 6N- 5E	3640	6825	NP	7235	7435	8110
120	HARRY	#1	26- 6N- 5E	3680	6830	NP	6885	7030	7790
121	BARTHOLOMEW	#1	4- 6N- 6E	ND	4030	NP	4055	NP	4180
122	HOLTHOUSE, JR., M.	#1-19	19- 6N- 6E	3330	5630	NP	5710	5930	6670
123	BOTTIMORE, R.L.	#1	3- 6N- 7E	ND	2520	NP	2530	NP	2650
124	GILL	#1	13- 6N- 7E	ND	2365	NP	2365	NP	2470
125	HOWARD	#1	24- 6N- 7E	ND	2510	NP	2510	NP	2650
126	TOLENAS FARMS	#1	20- 5N- 1W	520	1660	NP	1915	5020	NDE
127	PETERSEN	#1	32- 5N- 1E	8430	9885	NP	10060	ND	NDE
128	MCCORMACK-WILLIAMS.	#9	25- 5N- 4E	ND	9305	NP	9650	11510	12610
129	HOWARD FEE	#24-11	11- 5N- 5E	3935	7660	NP	7900	8250	8480
130	CAPITAL CO.	#6	27- 5N- 5E	3315	8365	NP	8740	9415	10220
131	CHEVRON-BLOSSOM CO.	#1-29	29- 5N- 5E	3840	9110	NP	9600	10990	NDE
132	THOMPSON	#2	33- 5N- 8E	ND	2835	NP	2835	NP	3000
133	MCCULLOCH-MACSON-S.	#1	10- 4N- 1W	3615	NP	NP	3615	6240	NDE
134	LAMBIE	#5	25- 4N- 1W	3085	3620	NP	3855	ND	NDE
135	COOK, JR., PETER	#16	10- 4N- 2E	6885	14225	NP	14565	NDE	NDE
136	COOK, JR., PETER	#13	12- 4N- 2E	7085	14550	NP	14920	NDE	NDE
137	COOK, JR., PETER	#15	8- 4N- 3E	4875	12490	NP	12835	NDE	NDE
138	COOK, JR., PETER	#11	18- 4N- 3E	6860	12540	NP	12910	NDE	NDE
139	COMMUNITY	#1-1	1- 4N- 6E	2740	4655	NP	4800	5260	5710
140	SHELL-BROVELLI	#1	4- 4N- 6E	3180	5920	NP	6315	6460	7280
141	STEFFAN FEE	#13-6	6- 4N- 6E	ND	7700	NP	7975	8110	NDE
142	FEIST	#1-7	7- 4N- 6E	ND	7790	NP	8230	8400	NDE
143	COMMUNITY	#2-1	12- 4N- 6E	2770	4740	NP	4930	5410	5690

ID	WELL NAME		LOCATION	Top K	Ks	Kk	F zone	Kd	bsmnt
144	WOODBRIDGE	#32-1	32- 4N- 6E	4030	8110	NP	8550	8750	9240
145	COMMUNITY	#1-18-5	5- 4N- 7E	ND	4360	NP	4405	4500	4640
146	GRUSSENDORF	#1	7- 4N- 7E	2730	4400	NP	4430	4645	4790
147	LODI COMMUNITY	#9-1	9- 4N- 7E	2550	4000	NP	4050	4280	4460
148	LODI COMMUNITY	#10-1	10- 4N- 7E	2545	3940	NP	3975	4260	4490
149	FERRERO	#1-10	10- 4N- 7E	ND	4000	NP	4040	4290	4480
150	THOMPSON	#1	11- 4N- 7E	ND	3935	NP	3935	4065	4315
151	COMMUNITY	#14-23-1	23- 4N- 7E	2575	3965	NP	3995	4220	NDE
152	LOCKE	#1	25- 4N- 7E	2335	3860	NP	3860	4065	4230
153	MONTGOMERY	#1	29- 4N- 8E	ND	3570	NP	3570	3730	3905
154	BOULDIN DEV.	#1	23- 3N- 4E	4750	11360	NDE	NDE	NDE	NDE
155	EAST LODI	#1-1	16- 3N- 7E	2970	5460	NP	5490	5675	6050
156	TERESI	#1	6- 3N- 8E	ND	3890	NP	3890	4095	4290
157	BREITENBUCHER, W.G.	#1	10- 3N- 8E	2400	3350	NP	3350	3510	3640
158	BENJAMIN	#1-2	1- 2N- 7E	ND	5140	NP	5140	5250	5380
159	MOORE	#12-2	12- 2N- 7E	ND	5175	NP	5175	5390	NDE
160	MARTINET	#25-2	2- 2N- 8E	2325	3935	NP	3935	4125	4230
161	L & W TRUSTEE	#1	3- 2N- 8E	ND	3985	NP	3985	4150	4280
162	ROBBINS	#1	19- 2N- 8E	2470	6235	NP	6440	6675	6970
163	EILERS	#1-32	32- 2N- 8E	1860	4780	NP	5335	7480	NDE
164	UNIT	#1-14X-36	36- 2N- 8E	2160	4710	NP	4710	4955	5070
165	MANTELLI	#1	14- 1N- 4E	5600	12535	NP	13215	14725	16220
166	FOLEY	#1	24- 1N- 5E	ND	11195	NP	11785	11975	12230
167	ARBINI	#1	13- 1N- 7E	2215	6290	NP	6885	8760	NDE
168	SIGNAL	#47-1	20- 1N- 7E	2665	8205	NP	8665	10265	10905
169	EAST STOCKTON	#1	3- 1N- 8E	1700	4915	NP	5425	7015	NDE
170	EAST STOCKTON	#1	5- 1N- 8E	1800	4980	NP	5585	7910	8520
171	TEXACO-CHEV.-FRANZ.	#1-33	33- 1N- 8E	2350	6845	NP	7350	9140	9630
172	SACCO-NECK-SOUZA	#1	17- 1S- 3E	ND	5380	NP	5775	NDE	NDE
173	LOUIS SOUZA	#1	19- 1S- 3E	NSE	NP	NP	NP	2780	NDE
174	NORRIS GRUNAUER	#1	26- 1S- 4E	ND	13010	NP	13395	NDE	NDE
175	LAWRENCE	#1	35- 1S- 5E	4090	11330	NP	11920	NDE	NDE
176	LATHROP	#B-5	7- 1S- 6E	3600	9675	NP	10435	12140	NDE
177	MACHADO	#1	36- 1S- 7E	3110	8740	NP	9020	NDE	NDE
178	FRANZIA	#1	8- 1S- 8E	ND	7435	NP	7800	9790	NDE
179	SIMMS	#1	9- 1S- 8E	2500	7440	NP	7690	9265	NDE
180	VIERRA	#1	17- 1S- 8E	2625	7535	NP	7855	9750	NDE
181	FRANZIA	#2	20- 1S- 8E	ND	7460	NP	7760	9555	NDE
182	COOKSON	#1	29- 1S- 8E	ND	7655	NP	7940	9900	NDE
183	CASTELLO	#1-13	13- 2S- 3E	NSE	NP	NP	NSE	2075	NDE
184	WEAVER CORDES	#1	26- 2S- 4E	2325	2345	NP	2720	6310	NDE
185	NOLA	#1	29- 2S- 4E	NSE	NP	NP	NSE	2510	NDE
186	TRACY COMMUNITY	#1-1	15- 2S- 5E	3385	11870	NP	12450	NDE	NDE
187	HAYES, L.H.	#24-1A	24- 2S- 6E	3645	11230	NP	11720	14900	15955
188	GILBERT	#1	3- 2S-10E	ND	ND	ND	ND	ND	4751
189	BRICHETTO	#1	28- 2S-10E	1850	5700	NP	5900	ND	6445
190	CLARIBELL	#1-32	32- 2S-11E	1930	NP	NP	NP	NP	4531
191	TF	#1-1	2- 3S- 4E	1635	1725	NP	2120	NDE	NDE

ID	WELL NAME		LOCATION	Top K	Ks	Kk	F zone	Kd	bsmnt
192	MCCULLOCH-COYNE ET	#1	10- 3S- 4E	NSE	NP	NP	NSE	3770	NDE
193	STEELE	#47-19	19- 3S- 5E	1550	4200	NP	4570	NDE	NDE
194	VERNALIS FARMS	#1	27- 3S- 6E	3490	11370	NP	11810	NDE	NDE
195	YOUNG COMMUNITY	#1	34- 3S- 8E	3260	10340	NP	10585	13055	13680
196	ALVES	#1	2- 3S- 9E	2490	7550	NP	7865	8920	9145
197	BRIGHT	#1	3- 3S-11E	1080	NP	NP	NP	NP	3178
198	METZGER	#1	23- 3S-11E	1040	NP	NP	NP	NP	3293
199	GREAT BASINS-CONNOL	#63X-5	5- 4S- 5E	NSE	4380	NP	4680	ND	NDE
200	NEEL	#1	12- 4S- 9E	3425	9515	NP	9515	NP	9760
201	BRADEN	#1	7- 4S-11E	2285	6550	NP	6550	NDE	NDE
202	GONSALVES	#1	36- 5S- 9E	3400	10765	NP	10960	ND	12307
203	WELL	#1	20- 5S-10E	NSE	9985	NP	10145	ND	11350
204	EVANS AND COOK	#1	23- 5S-11E	2730	NP	NP	NP	NP	6505
205	SOCO-RAPP	#1	28- 5S-11E	3125	NP	NP	NP	NP	7321

APPENDIX 2

MEASURED SECTIONS

EXPLANATION FOR MEASURED SECTION

Grain sizes:

C - clay
S - silt
V - very fine-grained sand
F - fine-grained sand
M - medium-grained sand
C - coarse-grained sand
V - very coarse-grained sand
G - granules
P - pebbles

<---INCREASING--- GRAIN SIZE

Paleocurrent: Arrows indicates restored azimuthal direction of flow with azimuthal value.

Facies: A, B, C, D, E, F, and G (from Mutti and Ricchi Lucchi, 1972)

Bouma divisions: a, b, c, d, and e (from Bouma, 1962)

Definitions:

massive - graded Bouma Ta division
planar - planar (or parallel) laminated
rippled - current ripple laminated

Symbols:

planar laminated

ripple laminated

convolute laminated

planar cross stratified

shale rip-up clasts

concretionary clasts

C concretionary bed

shells/shell fragments

dewatering structures

flame structures

bioturbated

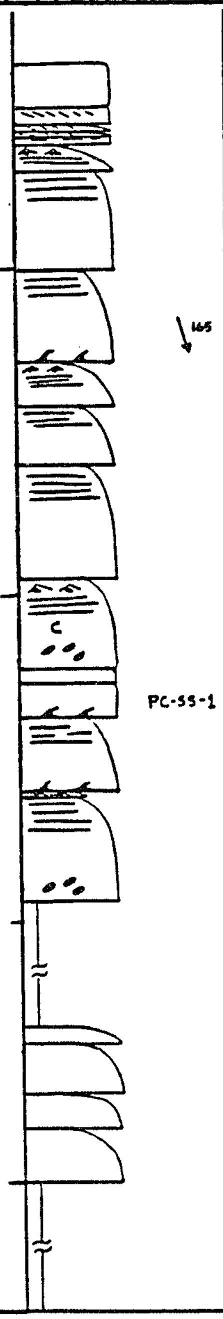
synsedimentary deformed bed

full thickness not represented

PC-SS-1 location of sandstone sample

A. PUTAH CREEK MEASURED SECTION

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.



THICKNESS (meters)	GRAIN SIZE C S VF M C VG P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		CHANNEL	Sandstone; massive	B	a
		CHANNEL	Sandstones (2); planar cross stratified	D	c
		CHANNEL	Sandstones (2); massive, planar; planar cross strat	B	abc
		CHANNEL	Sandstone; massive, planar, rippled	B	abc
		CHANNEL	Sandstone; massive, planar	B	ab
105	165	CHANNEL	Sandstone; massive, planar, flame structures	B	ab
		CHANNEL	Sandstone; massive, planar, rippled	B	abc
		CHANNEL	Sandstone; massive, planar	B	ab
		CHANNEL	Sandstone; massive, planar	B	ab
100		CHANNEL	Sandstone; massive, planar, rippled, shale ripup clasts, concretionary	B	abc
		CHANNEL	Sandstone; massive	3	a
	PC-55-1	CHANNEL	Sandstone; massive, flame structures	B	a
		CHANNEL	Sandstone; massive, planar, flame structures	B	ab
		CHANNEL	Sandstone; massive, planar rippled	B	abc
		CHANNEL	Sandstone; massive, planar, shale ripup clasts	B	ab
95		INTERCHANNEL?	Covered interval ~63m		
		INTERCHANNEL?	Sandstone; poorly exposed	B	?
		CHANNEL MARGIN	Sandstone; poorly exposed	B	?
		CHANNEL MARGIN	Sandstone; poorly exposed	B	?
		CHANNEL MARGIN	Sandstone; poorly exposed	B	?
30		INTERCHANNEL?	Covered interval ~30 m		
0					

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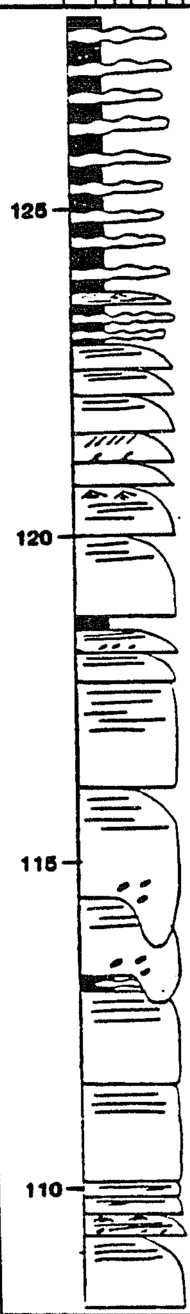


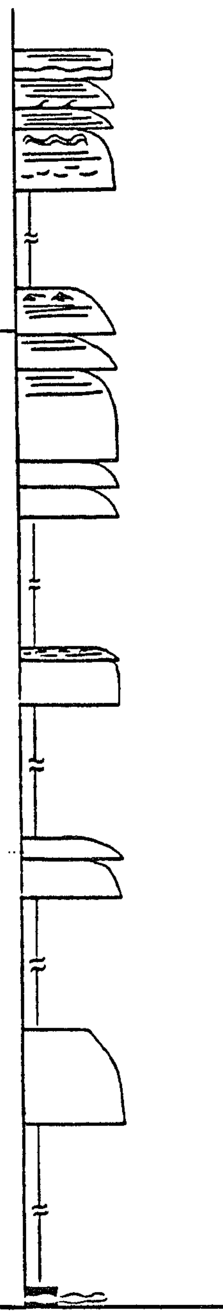
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
LEVEE	Interbedded sandstone and shale; 3:1	D,E,G	cde
	Sandstone; planar, rippled	D	bc
CHANNEL	Interbedded sandstone and shale; 3:1	E,G	cde
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; planar cross strat., flame structures	B	c
	Sandstone; massive	B	a
	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar	B	ab
	Shale	G	e
	Sandstone; massive, planar, shale rip-up clasts	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, shale rip-up clasts, erosional base	B	ab
	Sandstone; massive, planar, shale rip-up clasts, erosional base	B	ab
	Interbedded sandstone and shale; 9:1	E,G	cde
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstones (2); massive, planar	B	ab
	Sandstone; massive, planar, rippled, sh. ripup clasts	B	abc
	Sandstone; massive, planar	B	ab

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 3 of 19

THICKNESS (meters)

GRAIN SIZE
C S VF M C VG P

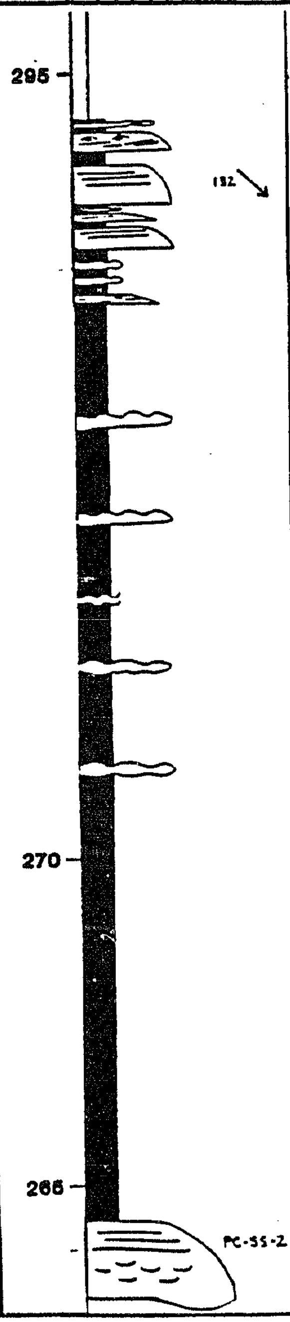
250



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Sandstone; planar	B	c
CHANNEL MARGIN	Sandstone; pinch and swell	E	c
	Sandstone; planar, flame structures	B	b
	Sandstone; planar	B	b
	Sandstone; planar, convolute laminations, dewatering structures	B	bc
INTERCHANNEL	Covered interval - 10.5 m		
CHANNEL MARGIN	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; poorly exposed	B	?
	Sandstone; poorly exposed	B	?
INTERCHANNEL ?	Covered interval - 9 m		
	Sandstone; massive, planar, rippled	C	abc
	Sandstone; massive, poorly exposed	C	a
	Covered interval - 90 m		
	Sandstone; poorly exposed	C	?
	Sandstone; poorly exposed	C	?
	Covered interval - 9 m		
CHANNEL ?	Sandstone; poorly exposed	B	?
INTERCHANNEL ?	Covered interval - 7.5 m		

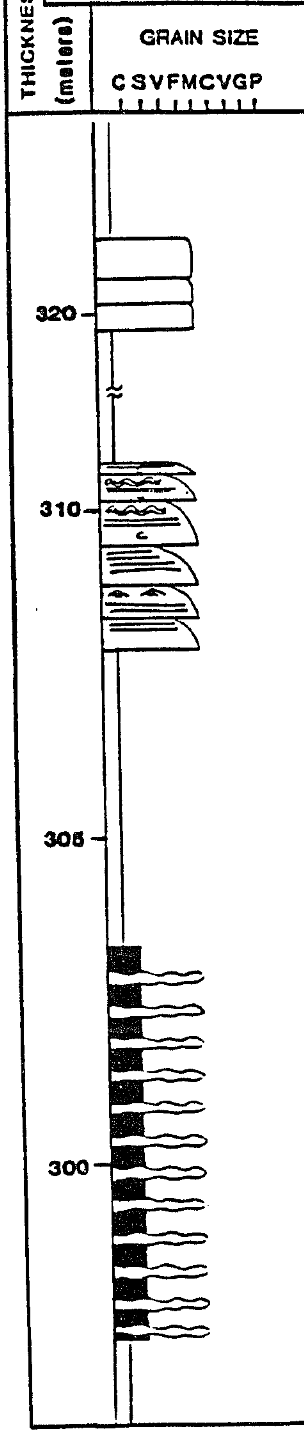
PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.

THICKNESS (meters) — GRAIN SIZE: C S VF M C VG P



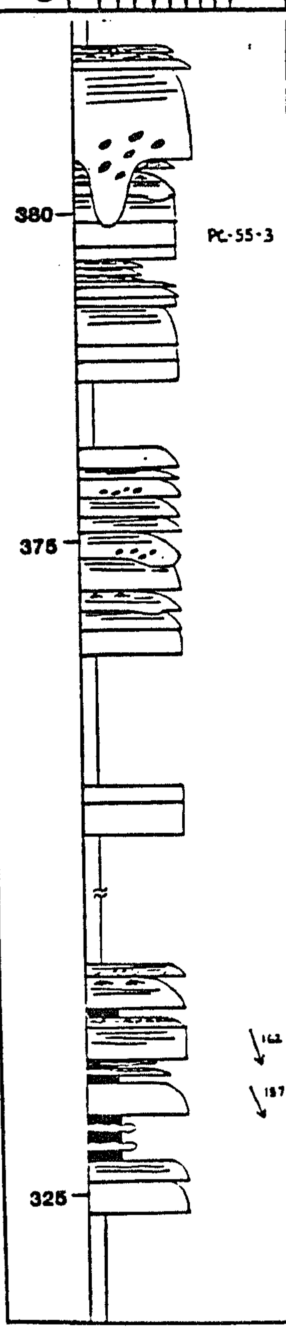
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
LEVEE	Covered interval		
	Interbedded sandstone and shale; 5:1	E,G	cde
	Sandstone; massive, planar, rippled	B	abc
	Shale	G	e
	Sandstone; massive, planar	B	ab
	Interbedded siltstone and shale; 1:1	E,G	cde
	Sandstone; planar	D	b
	Shale	G	e
	Sandstone; massive, planar	B	ab
	Interbedded siltstone and shale; 1:1	E,G	cde
	Sandstone; planar, rippled	D	bc
	Interbedded sandstone and shale; 1:7 21 m	D,E,G	cde
	Shale; poorly exposed	G	e
CHANNEL MARGIN	Sandstone; planar, dewatering structures	B	b

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.



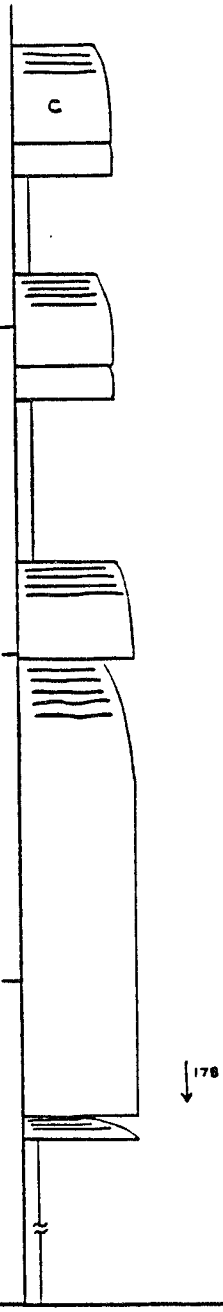
Facies Assoc.	Rock Description	Facies	Bouma Seq.
LEVEE	Covered interval		
LEVEE	Sandstone; poorly exposed	B	?
LEVEE	Sandstone; poorly exposed	B	?
LEVEE	Sandstone; poorly exposed	B	?
INTERCHANNEL	Covered interval – 9 m		
	Sandstone; planar, concretionary	D	b
LEVEE	Sandstone; planar, convolute laminations, concretionary	B	bc
LEVEE	Sandstone; massive, planar, convolute laminations, concretionary	B	abc
LEVEE	Sandstone; planar	B	b
LEVEE	Sandstone; planar, rippled	B	bc
LEVEE	Sandstone; massive, planar	B	ab
LEVEE	Covered interval		
LEVEE	Interbedded sandstone and shale; 1:1 pinch and swell	D,E,G	cde

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 6 of 19



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Sandstone; massive, planar, shale rip-up clasts	B	ab
	Sandstone; massive, planar, rippled	B	abc
CHANNEL MARGIN	Sandstone; massive	B	a
	Sandstone; massive, planar, shale ripup clasts	B	ab
	Sandstone; massive, planar, flame structures	B	ab
	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar	B	ab
	Sandstone; massive	B	a
	Sandstone; massive	B	a
	Sandstones (3); massive, planar, poorly exposed	B	ab
	Sandstone; massive, poorly exposed	B	a
	Sandstone; massive	B	a
	Sandstone; massive, planar	B	ab
	Sandstone; massive	B	a
	Sandstone; massive	B	a
	Covered interval		
	Sandstone; massive	B	a
	Sandstone; massive, planar	B	ab
	Sandstone; massive, shale rip-up clasts	B	a
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, shale rip-up clasts	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, rippled	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive	B	a
INTERCHANNEL?	Covered interval		
	Sandstone; massive, poorly exposed	C	?
	Sandstone; massive, poorly exposed	C	?
	Covered interval ~42 m		
	Sandstone; massive, planar, shale rip-up clasts; [illegible]	B	ab
	Sandstone; massive, planar, rippled	B	abc
	Shale	G	e
LEVEE	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar	B	ab
	Interbedded sandstone and shale; 5:1	E,G	cae
	Sandstone; planar	D	b
	Shale	G	e
	Sandstone; massive	B	a
	Interbedded siltstone and shale; 2:1	E,G	cae
	Sandstone; massive, planar	B	ab
	Sandstone; massive, poorly exposed	B	a
	Covered interval		

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.

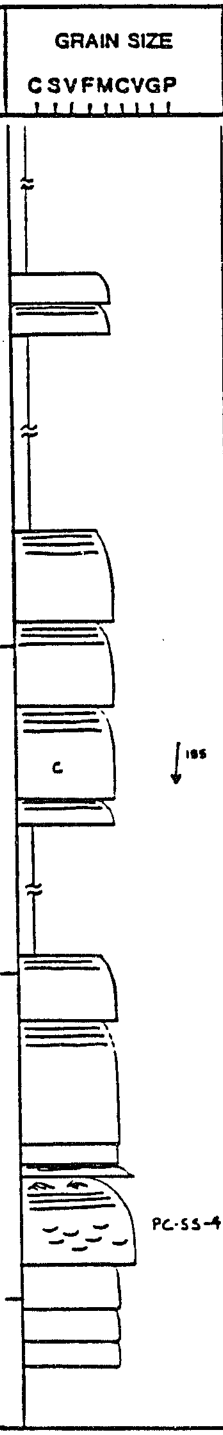


THICKNESS (meters)	GRAIN SIZE C SVFMCVGP	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		CHANNEL	Sandstone; massive, planar, concretionary	B	ab
		CHANNEL	Sandstone; massive	B	a
		CHANNEL	Covered interval		
435		CHANNEL	Sandstone; massive, planar	B	ab
		CHANNEL	Sandstone; massive	B	a
		CHANNEL	Covered interval		
		CHANNEL	Sandstone; massive, planar	B	ab
430		CHANNEL	Sandstone; massive, planar	B	ab
425		CHANNEL			
		CHANNEL	Sandstone; massive, planar	B	ab
		INTERCHANNEL?	Covered interval – 40 m		

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 8 of 19

THICKNESS (meters)	GRAIN SIZE C S VF M C VG P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		CHANNEL	Sandstone; massive	B	a
			Sandstone; massive	B	a
			Sandstone; massive	B	a
			Sandstone; massive, planar	B	ab
			Sandstone; massive, shale rip-up clasts	B	a
			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
455			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar, rippled	B	ab
			Sandstone; massive, planar, shale rip-up clasts	B	ab
			Sandstone; massive	B	a
			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
			Sandstone; massive	B	a
			Sandstone; massive	B	a
			Sandstone; massive, planar	B	ab
450			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
			Covered interval		
			Sandstone; massive	B	a
			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
			Covered interval		
			Sandstone; massive	B	a
445		INTERCHANNEL?	Covered interval		
440		CHANNEL	Sandstone; massive, covered at top	B	a

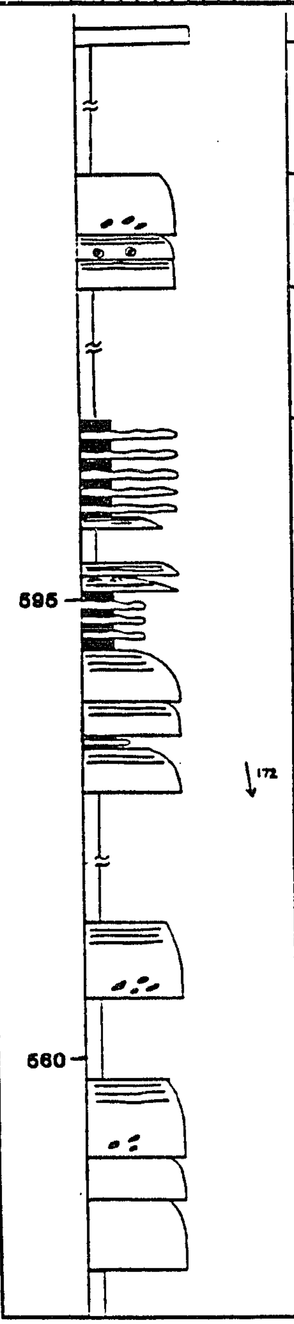
PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 9 of 19



THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	INTERCHANNEL?	Covered interval - 54 m		
	INTERCHANNEL?	Sandstone; massive, poorly exposed	C	a
	INTERCHANNEL?	Sandstone; massive, planar, poorly exposed	C	ab
	INTERCHANNEL?	Covered interval - 20 m		
	CHANNEL	Sandstone; massive, planar	B	ab
480	CHANNEL	Sandstone; massive, planar	B	ab
	CHANNEL	Sandstone; massive, planar, concretionary	B	ab
	CHANNEL	Sandstone; massive, planar	B	ab
	INTERCHANNEL?	Covered interval - 12 m		
465	CHANNEL	Sandstone; massive, planar, top covered	B	ab
	CHANNEL	Sandstone; massive, planar, concretionary	B	ab
	CHANNEL	Sandstone; massive	B	a
	CHANNEL	Sandstone; massive, planar	B	ab
	CHANNEL	Sandstone; massive, planar, rippled, dewatering structures	B	abc
460	CHANNEL	Sandstone; massive	B	a
	CHANNEL	Sandstone; massive	B	a
	CHANNEL	Sandstone; massive	B	a

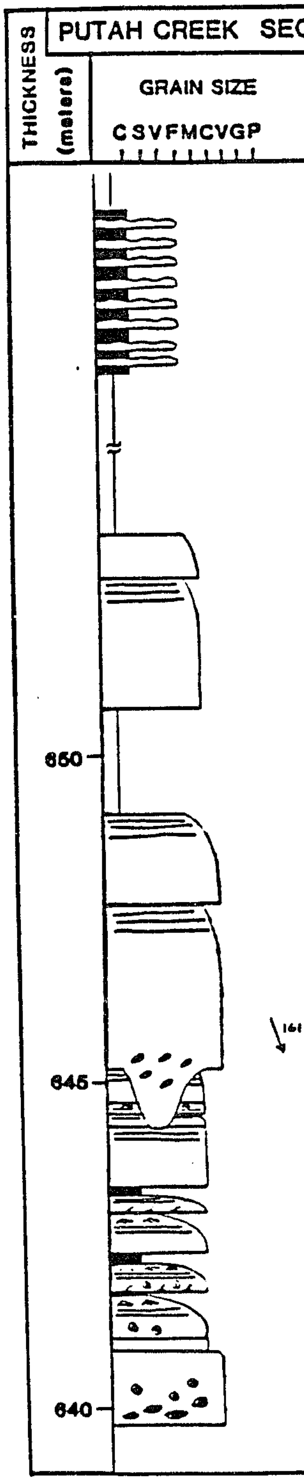
PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 10 of 19

THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



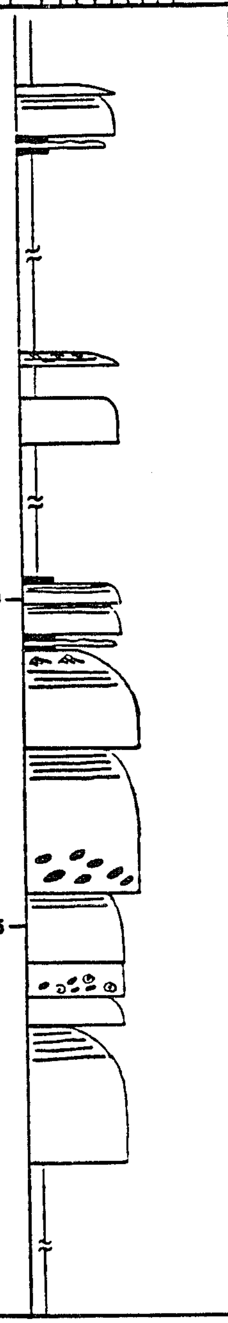
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Sandstone; massive	B	a
INTERCHANNEL?	Covered interval - 12m		
CHANNEL MARGIN	Sandstone; massive, shale rip-up clasts	B	a
CHANNEL MARGIN	Sandstone; massive, planar, concretionary clasts	B	ab
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
INTERCHANNEL?	Covered interval - 28 m		
LEVEE	Interbedded sandstone and shale; 5:1	E.6	cde
LEVEE	Sandstone; massive, planar	B	ab
LEVEE	Covered interval		
LEVEE	Sandstone; planar	D	b
LEVEE	Sandstone; massive, planar, rippled	B	abc
LEVEE	Interbedded sandstone and shale; 7:1	E.6	cde
LEVEE	Sandstone; massive, planar	B	ab
LEVEE	Sandstone; massive, planar	B	ab
LEVEE	Interbedded siltstone and shale; 1:1	E.6	cde
LEVEE	Sandstone; massive, planar	B	ab
INTERCHANNEL?	Covered interval - 30m		
CHANNEL	Sandstone; massive, planar, shale rip-up clasts, poorly exposed	B	ab
CHANNEL	Covered interval		
CHANNEL	Sandstone; massive, planar, shale rip-up clasts, poorly exposed	B	ab
CHANNEL	Sandstone; massive, poorly exposed	B	a
CHANNEL	Sandstone; massive, poorly exposed	B	a
	Covered interval		

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 11 of 19



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
LEVEE	Covered interval		
LEVEE	Interbedded sandstone and shale; 5:1	E,G	cde
INTERCHANNEL?	Covered interval - 7.5 m		
CHANNEL	Sandstone; massive, poorly exposed	B	a
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Covered interval	B	ab
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Sandstone; massive, planar, shale rip-up clasts	B	ab
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
CHANNEL MARGIN	Sandstone; massive planar rippled	B	ab
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
CHANNEL MARGIN	Shale	G	e
CHANNEL MARGIN	Sandstone; massive, planar flame structures	B	ab
CHANNEL MARGIN	Sandstone; massive, planar rippled	B	abc
CHANNEL MARGIN	Shale	G	e
CHANNEL MARGIN	Sandstone; planar, rippled, flame structures, concretionary clasts	B	bc
CHANNEL MARGIN	Sandstone; massive, planar, rippled, concretionary clasts	B	abce
CHANNEL MARGIN	Sandstone; massive	B	a
CHANNEL MARGIN	Sandstone; massive, concretionary clasts, shell fragments	B	a

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 12 of 19



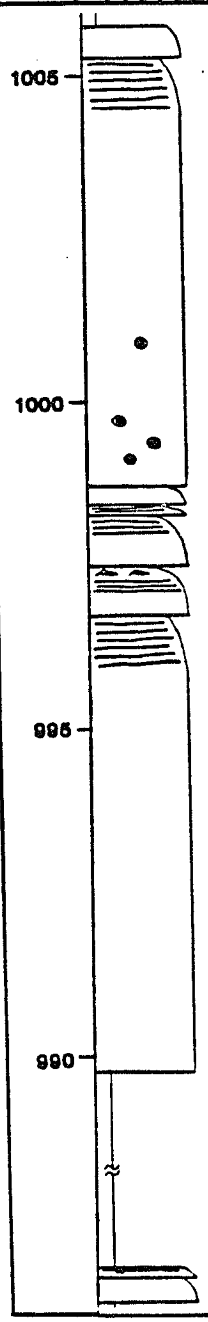
THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	LEVEE	Covered interval		
		Sandstone; massive, poorly exposed	B	a
		Sandstone: massive, planar	B	ab
		Interbedded sandstone and shale; 1:2	E,G	cde
	INTERCHANNEL ?	Covered interval - 24 m		
		Sandstone; massive, planar, rippled	C	abc
		Covered interval		
		Sandstone; massive, poorly exposed	C	a
		Covered interval - 8 m		
		Shale	G	e
	CHANNEL	Sandstone: massive, planar	B	ab
680		Sandstone; massive, planar	B	ab
		Interbedded sandstone and shale; 1:1	E,G	cde
		Sandstone: massive, planar, rippled	B	abc
		Sandstone; massive, planar, shale rip-up clasts	B	ab
675		Sandstone, massive, planar	B	ab
		Sandstone: massive, shale rip-up clasts, concretionary clasts	B	a
		Sandstone: massive	B	a
		Sandstone; massive, planar	B	abe
	LEVEE	Covered interval - 8 m		

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 13 of 19

THICKNESS (meters)	GRAIN SIZE C S VF F M C VC G P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		INTERCHANNEL?	Covered interval ~60m		
770		CHANNEL/ CHANNEL MARGIN	Sandstone; massive, planar, rippled	B	abc
			Sandstone; massive, planar, rippled	B	abc
			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
		INTERCHANNEL?	Covered interval ~40m		
		CHANNEL	Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
725	PC-SS-5		Sandstone; massive, planar	B	ab
			Sandstone; massive, planar, rippled	B	abc
			Sandstone; massive, planar	B	ab
			Sandstone; massive, planar	B	ab
720			Sandstone; massive	B	a
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
		LEVEE	Covered interval		

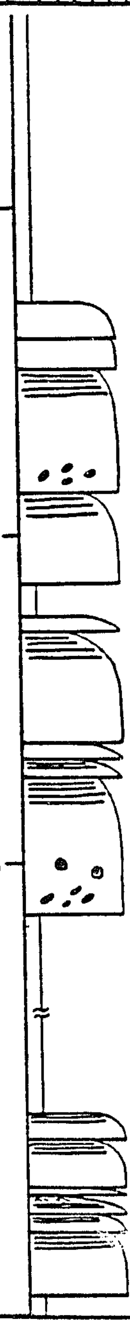
PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 14 of 19

THICKNESS (meters) | GRAIN SIZE: C S VF F M C VG P

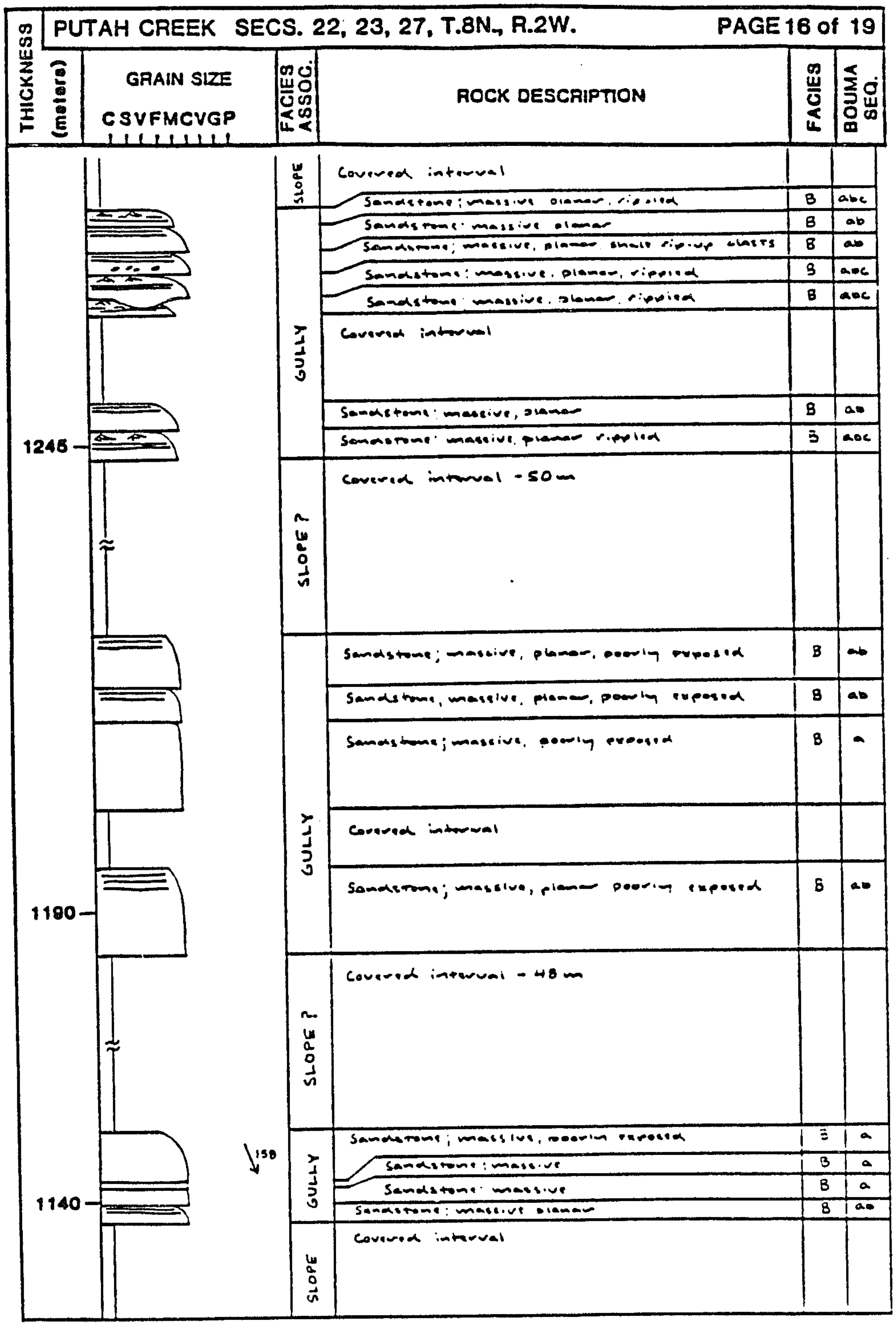


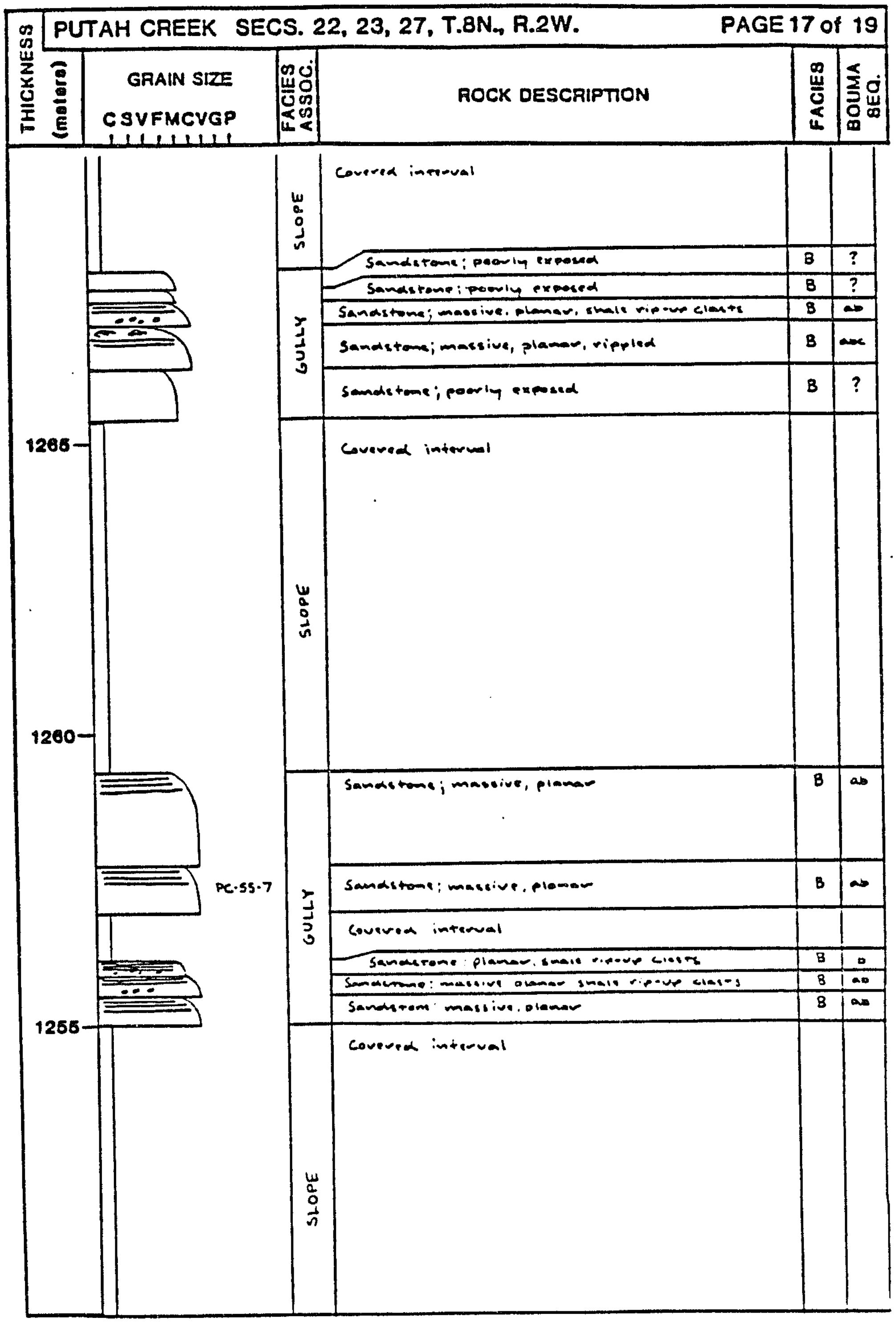
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
CHANNEL	Sandstone; massive, top covered	B	a
CHANNEL	Sandstone; massive, planar, concretionary clasts	B	ab
CHANNEL	Sandstone; massive, poorly exposed	B	a
CHANNEL	Sandstone; planar	B	b
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
CHANNEL	Sandstone; massive, planar, rippled	B	abc
CHANNEL	Sandstone; massive, planar	B	ab
INTERCHANNEL ?	Covered interval – 159 m		
INTERCHANNEL ?	Sandstone; massive, planar, poorly exposed	C	ab
INTERCHANNEL ?	Sandstone; massive, poorly exposed	C	a

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 15 of 19

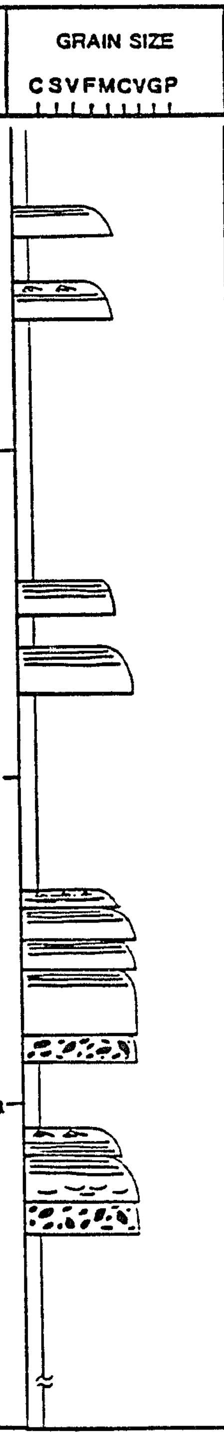


THICKNESS (meters)	GRAIN SIZE C S VF M C VG P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
1135		SLOPE	Covered interval		
		GULLY	Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, planar, shale rip-up clasts	B	ab
1130			Sandstone; massive, planar	B	ab
			Covered interval		
			Sandstone, massive, poorly exposed	B	a
			Sandstone; massive, planar	B	ab
			Sandstone; massive, poorly exposed	B	a
			Sandstone; massive, planar	B	ab
1125			Sandstone; massive planar, shale rip-up clasts, concretionary clasts	B	ab
		SLOPE?	Covered interval ~115 m.		
		CHANNEL	Sandstone; massive planar	B	ab
			Sandstone; massive, planar	B	ab
			Sandstone; massive	B	a
			Sandstone; massive, planar rippled	B	abc
			Sandstone; massive, planar	B	ab
	PC-55-6		Sandstone; massive, planar	B	ab
			Covered interval		


PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.
PAGE 16 of 19
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
SLOPE
Covered interval
Sandstone; massive planar, rippled B abc
Sandstone: massive planar B ab
Sandstone; massive, planar shale rip-up clasts B ab
Sandstone: massive, planar, rippled B abc
Sandstone massive, planar, rippled B abc
GULLY
Covered interval
Sandstone: massive, planar B ab
Sandstone: massive, planar rippled B abc
1245
SLOPE ?
Covered interval - 50 m
GULLY
Sandstone; massive, planar, poorly exposed B ab
Sandstone, massive, planar, poorly exposed B ab
Sandstone; massive, poorly exposed B a
Covered interval
Sandstone; massive, planar poorly exposed B ab
1190
SLOPE ?
Covered interval - 48 m
GULLY
158
Sandstone; massive, poorly exposed B a
Sandstone: massive B a
Sandstone: massive B a
Sandstone: massive planar B ab
1140
SLOPE
Covered interval


PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.
PAGE 17 of 19
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
SLOPE
Covered interval
GULLY
Sandstone; poorly exposed
B
?
Sandstone; poorly exposed
B
?
Sandstone; massive, planar, small rip-up clasts
B
ab
Sandstone; massive, planar, rippled
B
abc
Sandstone; poorly exposed
B
?
1265
SLOPE
Covered interval
1260
GULLY
Sandstone; massive, planar
B
ab
PC-55-7
Sandstone; massive, planar
B
ab
Covered interval
Sandstone; planar, small rip-up clasts
B
b
Sandstone; massive planar small rip-up clasts
B
ab
Sandstone; massive, planar
B
ab
1255
SLOPE
Covered interval

PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W. PAGE 18 of 19

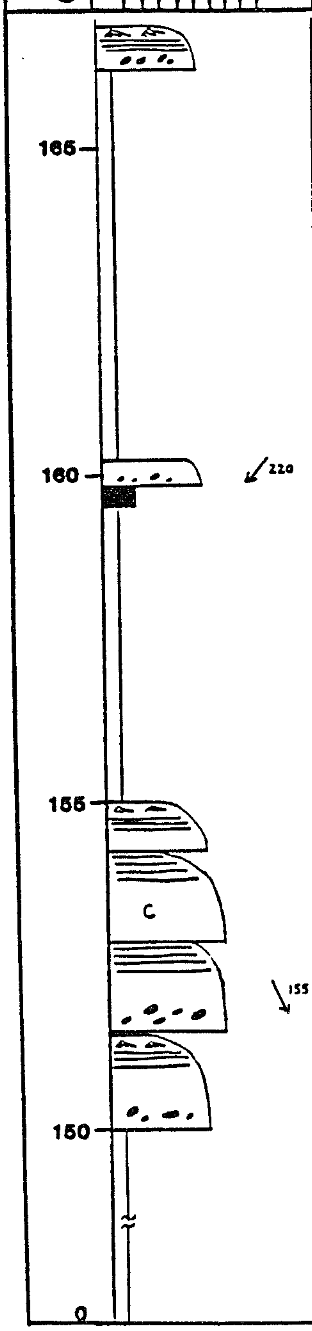


THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	SLOPE	Covered interval		
	GULLY	Sandstone; massive, planar	B	ab
	GULLY	Covered interval		
	GULLY	Sandstone; massive, planar, rippled	B	abc
1360	SLOPE	Covered interval		
	GULLY	Sandstone; massive, planar	B	ab
	GULLY	Covered interval		
	GULLY	Sandstone; massive, planar	B	ab
1355	SLOPE	Covered interval		
	GULLY	Sandstone massive, planar, rippled	B	abc
	GULLY	Sandstone; massive, planar	B	ab
	GULLY	Sandstone; massive, planar	B	ab
	GULLY	Sandstone, massive, planar	B	ab
	GULLY	Shale rip-up-clast conglomerate	A	a
1350	GULLY	Covered interval		
	GULLY	Sandstone; planar rippled	B	bc
	GULLY	Sandstone; massive, planar, dewatering structures	B	ab
	GULLY	Shale rip-up-clast conglomerate	A	a
	SLOPE ?	Covered interval - 80 m		

THICKNESS (meters)	PUTAH CREEK SECS. 22, 23, 27, T.8N., R.2W.			PAGE 19 of 19	
	GRAIN SIZE C S VF M C VG P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
1604		SLOPE ?	Covered interval; some scattered outcrops of shale - 240 m		

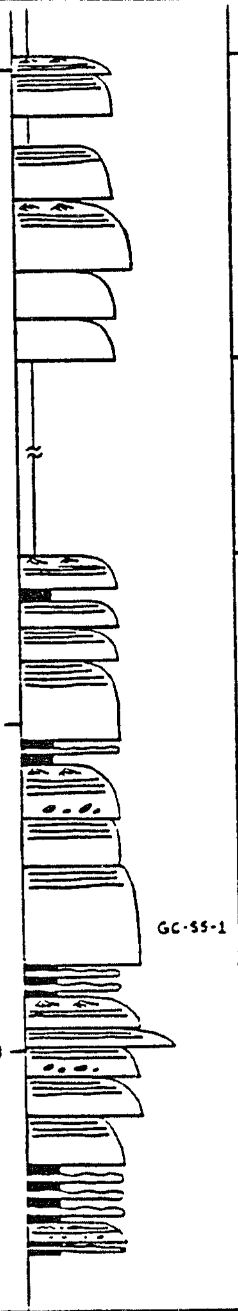
B. GATES CANYON MEASURED SECTION

GATES CANYON SECS. 11, 12, T.6N., R.2W. PAGE 1 of 11

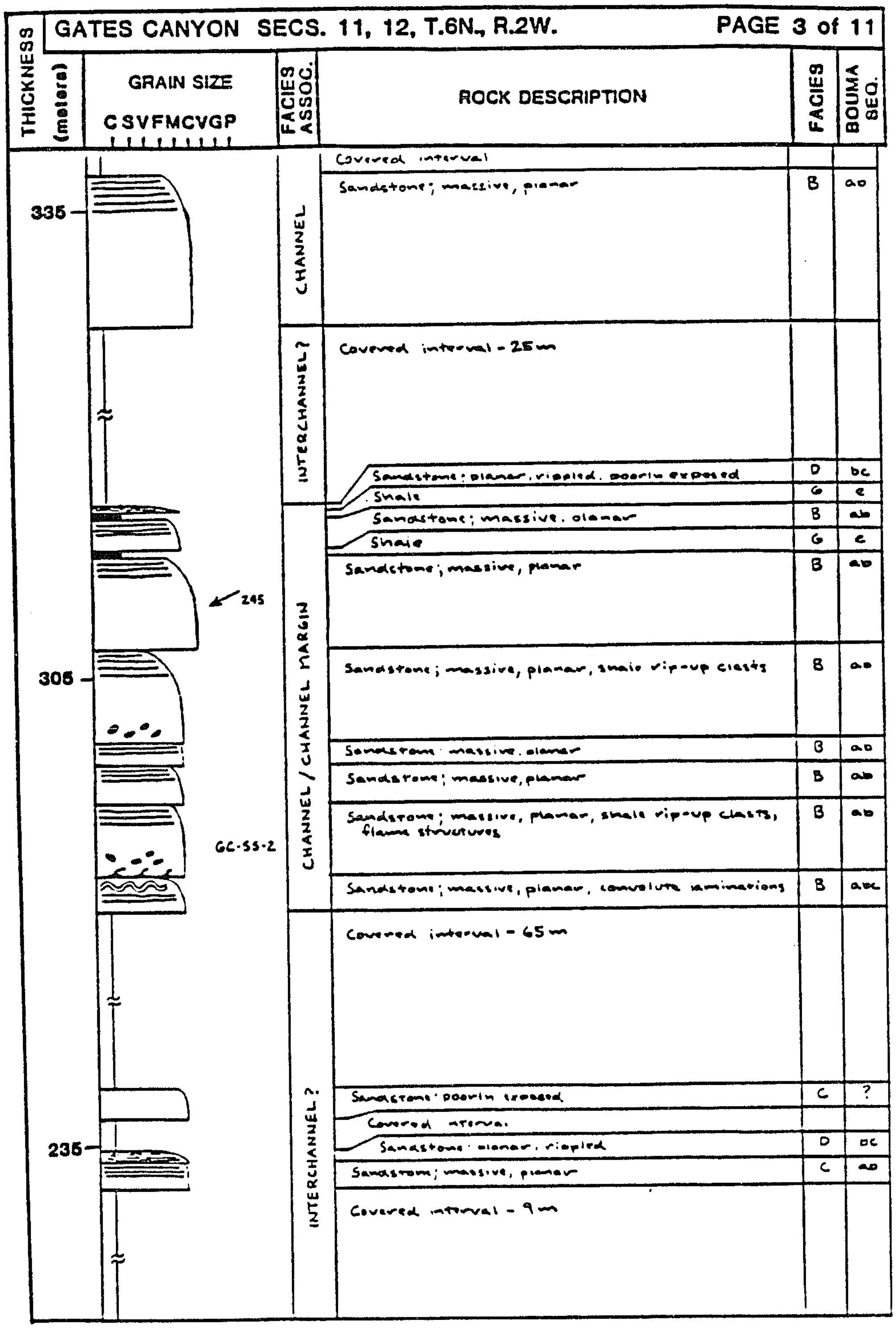


FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
LEVEE	Sandstone; massive, planar, rippled, shale rip-up clasts	B	abc
INTERCHANNEL ?	Covered interval		
	Sandstone; massive, shale rip-up clasts, top covered	C	a
	Shale	G	e
	Covered interval		
CHANNEL / CHANNEL MARGIN	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar, convolutionary	B	ab
	Sandstone, massive, planar, shale rip-up clasts	B	ab
	Sandstone; massive, planar, rippled, shale rip-up clasts	B	abce
INTERCHANNEL ?	Covered interval - 150m		

GATES CANYON SECS. 11, 12, T.6N., R.2W.

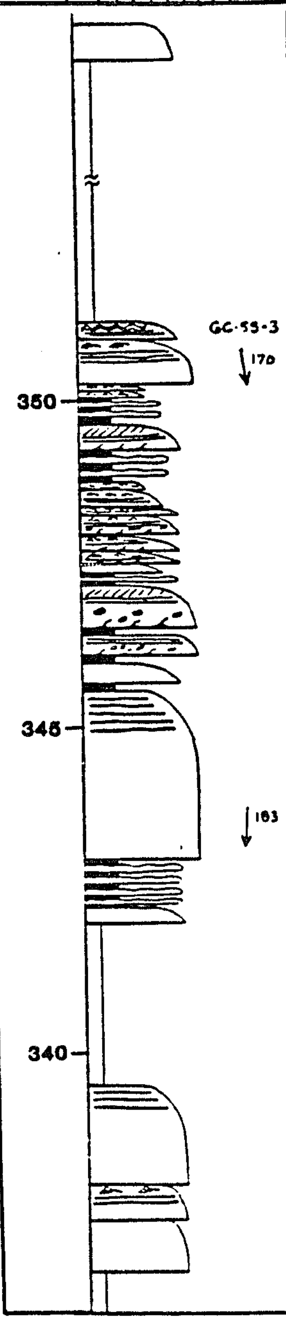


THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		Covered interval		
	CHANNEL/CHANNEL MARGIN	Sandstone: massive, planar rippled	B	abc
225		Sandstone: massive, planar, poorly exposed	B	ab
		Covered interval		
		Sandstone; massive, planar	B	ab
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, poorly exposed	B	a
		Sandstone; massive, poorly exposed	B	a
	INTERCHANNEL ?	Covered interval ~43 m		
	CHANNEL	Sandstone; massive, planar, rippled	B	abc
		Shale	G	e
		Sandstone: massive, planar	B	ab
		Sandstone: massive planar	B	ab
		Sandstone; massive, planar	B	ab
175		Interbedded sandstone and shale; 1:3	E,G	cde
		Sandstone; massive, planar, rippled, shale ripup clasts	B	ab
		Sandstone; massive, planar	B	ab
		Sandstone; massive, planar	B	ab
	LEVEE	Interbedded sandstone and shale; 5:1	E,G	cde
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, planar	B	ab
170		Sandstone; massive, planar shale rip-up clasts	B	ab
		Sandstone: massive, planar	B	ab
		Sandstone; massive, planar	B	ab
		Interbedded sandstone and shale; 5:1	E,G	cde
		Sandstone; massive, planar, rippled, shale ripup clasts	B	abc
		Interbedded sandstone and shale; 5:1	E,G	cde


GATES CANYON SECS. 11, 12, T.6N., R.2W.
PAGE 3 of 11
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
335
305
235
245
GC-SS-2
CHANNEL
INTERCHANNEL?
CHANNEL / CHANNEL MARGIN
INTERCHANNEL?
Covered interval
Sandstone; massive, planar B ab
Covered interval - 25m
Sandstone; planar, rippled, poorly exposed D bc
Shale G e
Sandstone; massive, planar B ab
Shale G e
Sandstone; massive, planar B ab
Sandstone; massive, planar, shale rip-up clasts B ab
Sandstone; massive, planar B ab
Sandstone; massive, planar B ab
Sandstone; massive, planar, shale rip-up clasts, flame structures B ab
Sandstone; massive, planar, convolute laminations B abc
Covered interval - 65m
Sandstone; poorly exposed C ?
Covered interval
Sandstone; planar, rippled D bc
Sandstone; massive, planar C ab
Covered interval - 9m

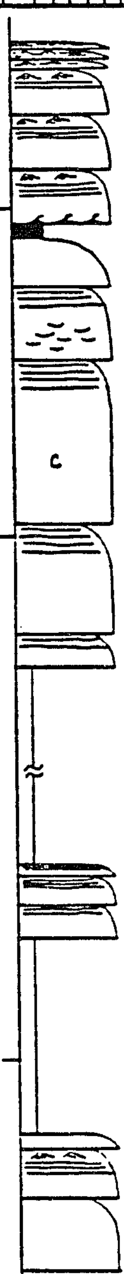
GATES CANYON SECS. 11, 12, T.6N., R.2W. **PAGE 4 of 11**

THICKNESS (meters) — GRAIN SIZE C S VF M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Sandstone, poorly exposed	B	?
INTERCHANNEL ?	Covered interval ~115 m		
	Sandstone; massive, planar, convolute laminations	B	abc
	Sandstone; massive, planar, rippled	B	abc
	Sandstone; rippled	D	c
	Sandstone; rippled	D	c
	Interbedded sandstone and shale; 3:1	E,G	cde
	Sandstone; massive, planar, planar cross laminations, flame structures	B	abc
	Interbedded sandstone and shale; 3:1	E,G	cde
CHANNEL MARGIN	Sandstone; planar, rippled	D	bc
	Sandstone; planar, rippled	D	bc
	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar, rippled, shale ripup clasts, flame structures	B	abc
	Sandstone; massive, planar, rippled, flame structures	B	abc
	Sandstone; massive, planar, rippled, flame structures	B	abc
CHANNEL	Sandstone; planar, rippled	D	bc
	Interbedded sandstone and shale; 5:1	E,G	cde
	Sandstone; massive, planar, planar cross laminations, shale ripup clasts, flame structures	B	abc
	Shale	G	e
	Sandstone; massive, planar, shale ripup clasts, flame structures	B	ab
	Shale	G	e
	Sandstone; poorly exposed	B	?
	Shale	G	e
	Sandstone; massive, planar	B	ab
LEVEE	Interbedded sandstone and shale; 1:1	E,G	cde
	Sandstone; poorly exposed	B	?
	Covered interval		
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
	Sandstone; massive, planar, rippled, poorly exposed	B	abc
	Sandstone; massive, poorly exposed	B	a
	Covered interval		

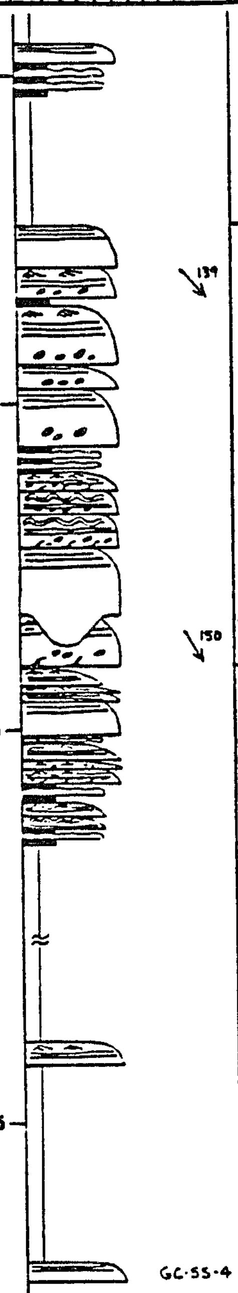
GATES CANYON SECS. 11, 12, T.6N., R.2W. PAGE 5 of 11



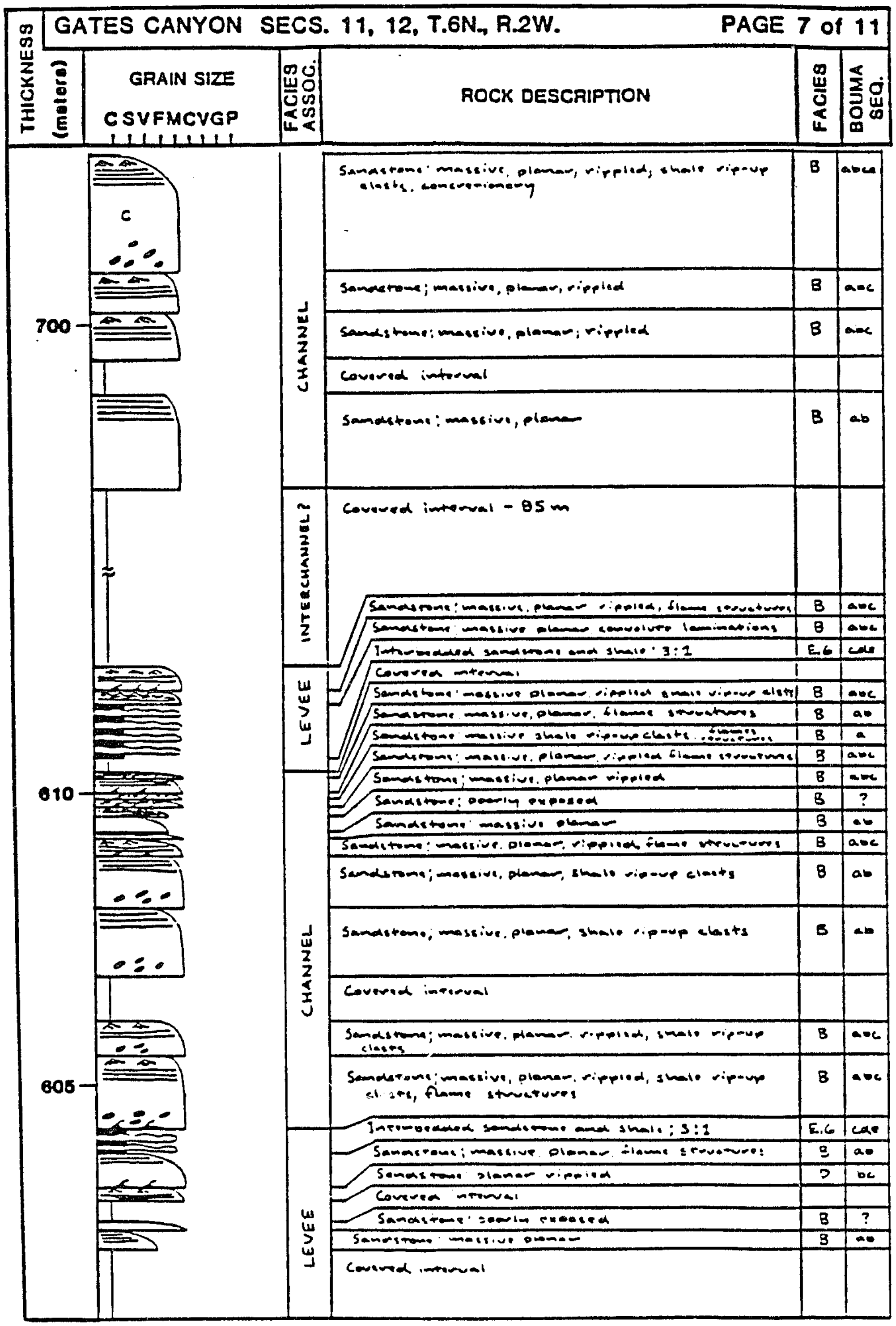
THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	CHANNEL	Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, planar, rippled.	B	abc
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; massive, planar, rippled, flame structures	B	abc
530		Shale	6	e
		Sandstone; poorly exposed	B	?
		Sandstone; massive, planar, dewatering structures	B	ab
		Sandstone; massive, planar, concretionary	B	ab
525		Sandstone; massive, planar	B	ab
		Sandstone; massive, planar	B	ab
	INTERCHANNEL?	Covered interval - 50 m		
		Sandstone; massive, planar	B	ab
	CHANNEL/CHANNEL MARGIN	Sandstone; massive, planar	B	ab
		Sandstone; massive, planar	B	ab
470		Covered interval		
		Sandstone; poorly exposed	B	?
		Sandstone; massive, planar, rippled	B	abc
		Sandstone; poorly exposed	B	?

GATES CANYON SECS. 11, 12, T.6N., R.2W. PAGE 6 of 11

THICKNESS (meters) | GRAIN SIZE C S VF F M C VG P

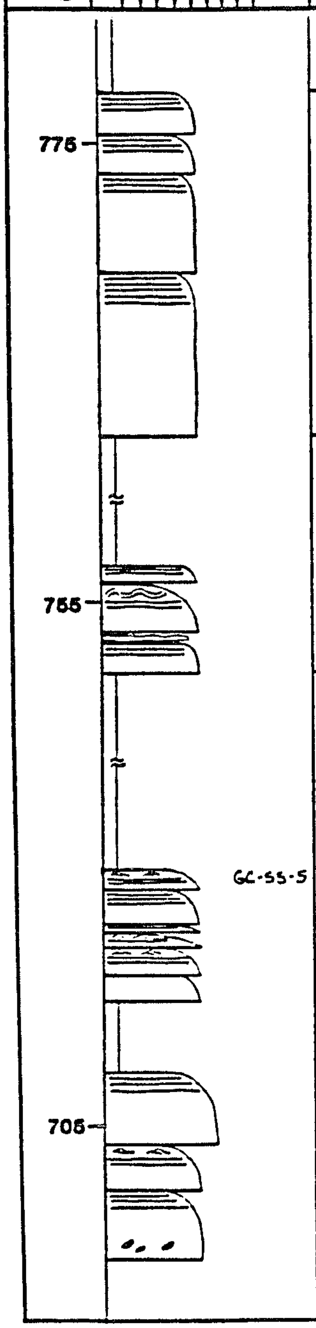


Thickness (meters)	Facies Assoc.	Rock Description	Facies	Bouma Seq.
	Levee	Covered interval		
	Levee	Sandstone; massive, planar	B	ac
600	Levee	Interbedded sandstone and shale; 1:1	E,G	cde
	Levee	Covered interval		
	Channel	Sandstone; massive, planar	B	ab
	Channel	Sandstone; planar, rippled, shale rip-up clasts	B	bc
	Channel	Shale	G	e
	Channel	Sandstone; massive, planar, rippled, shale rip-up clasts	B	abc
	Channel	Sandstone; massive, planar; shale rip-up clasts	B	ab
	Channel	Sandstone; massive, planar, shale rip-up clasts	B	ab
595	Channel	Interbedded sandstone and shale; 7:1	E,G	cde
	Channel	Sandstone; massive, planar; rippled, shale rip-up clasts, flame structures	B	abc
	Channel	Sandstone; planar, convolute laminations, shale rip-up clasts	B	bc
	Channel	Sandstone; planar, convolute laminations, shale rip-up clasts, flame structures	B	bc
	Channel	Sandstone; massive, planar	B	ab
	Channel	Sandstone; massive, planar, rippled, shale rip-up clasts, flame structures	B	abc
	Channel	Sandstone; planar, rippled	D	bce
	Channel	Sandstone; planar, rippled	D	bc
	Channel	Sandstone; planar	D	b
	Channel	Sandstone; massive, planar	B	ab
	Channel	Interbedded sandstone and shale; 1:1	E,G	cde
	Levee	Sandstone; massive, planar, rippled	B	abc
	Levee	Sandstone; rippled, shale rip-up clasts	D	c
590	Levee	Sandstone; massive, planar, shale rip-up clasts, flame struct.	B	ab
	Levee	Interbedded sandstone and shale; 7:1	E,G	cde
	Levee	Sandstone; massive, planar, rippled	B	abc
	Levee	Sandstone; massive, planar, convolute laminations	B	abc
	Levee	Interbedded sandstone and shale; 1:1	E,G	cde
	Interchannel?	Covered interval – 52 m		
	Interchannel?	Sandstone; massive, planar, rippled	C	abc
535	Interchannel?	Covered interval		
	Interchannel?	Sandstone; massive, planar	B	ab


GATES CANYON SECS. 11, 12, T.6N., R.2W.
PAGE 7 of 11
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
700
610
605
c
CHANNEL
INTERCHANNEL?
LEVEE
CHANNEL
LEVEE
Sandstone: massive, planar, rippled, shale rip-up clasts, concretionary
B
abce
Sandstone; massive, planar, rippled
B
abc
Sandstone; massive, planar; rippled
B
abc
Covered interval
Sandstone; massive, planar
B
ab
Covered interval - 85 m
Sandstone; massive, planar rippled, flame structures
B
abc
Sandstone: massive planar convolute laminations
B
abc
Interbedded sandstone and shale: 3:1
E.6
cde
Covered interval
Sandstone: massive planar, rippled shale rip-up clasts
B
abc
Sandstone massive, planar, flame structures
B
ab
Sandstone massive shale rip-up clasts, flame structures
B
a
Sandstone; massive, planar, rippled flame structures
B
abc
Sandstone; massive, planar rippled
B
abc
Sandstone; poorly exposed
B
?
Sandstone: massive planar
B
ab
Sandstone; massive, planar, rippled, flame structures
B
abc
Sandstone; massive, planar, shale rip-up clasts
B
ab
Sandstone; massive, planar, shale rip-up clasts
B
ab
Covered interval
Sandstone; massive, planar, rippled, shale rip-up clasts
B
abc
Sandstone; massive, planar, rippled, shale rip-up clasts, flame structures
B
abc
Interbedded sandstone and shale; 3:1
E.6
cde
Sandstone; massive planar, flame structures
B
ab
Sandstone planar rippled
D
bc
Covered interval
Sandstone: poorly exposed
B
?
Sandstone: massive planar
B
ab
Covered interval

GATES CANYON SECS. 11, 12, T.6N., R.2W.

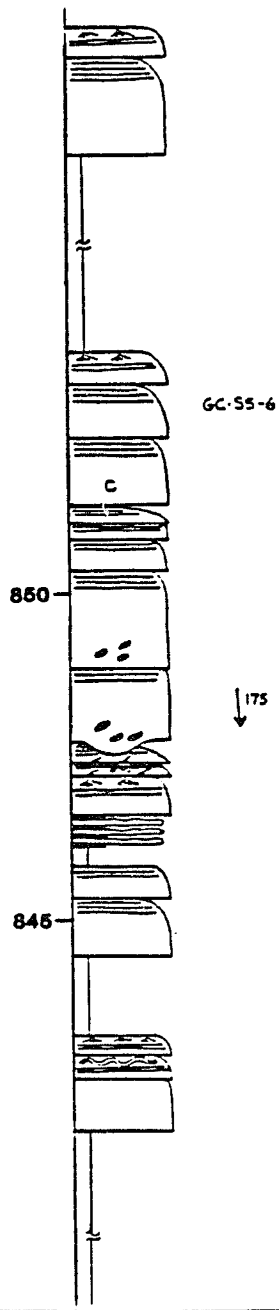
THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Covered interval		
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Sandstone; massive, planar	B	ab
LEVEE?	Covered interval – 15m		
LEVEE?	Sandstone; massive, planar	B	ab
LEVEE?	Sandstone planar convolute laminations	B	bce
LEVEE?	Interbedded sandstone and shale; 1:1	E,G	cde
LEVEE?	Sandstone massive, planar, base covered	B	ab
INTERCHANNEL?	Covered interval – 45 m		
INTERCHANNEL?	Sandstone; massive, planar, rippled	B	abc
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Sandstone; massive, planar rippled	B	abc
CHANNEL	Sandstone; massive, planar, rippled	B	abc
CHANNEL	Sandstone; massive	B	a
CHANNEL	Covered interval		
CHANNEL	Sandstone; massive, planar	B	ab
CHANNEL	Sandstone; massive, planar, rippled	B	abc
CHANNEL	Sandstone; massive, planar, shale ripup clasts	B	ab

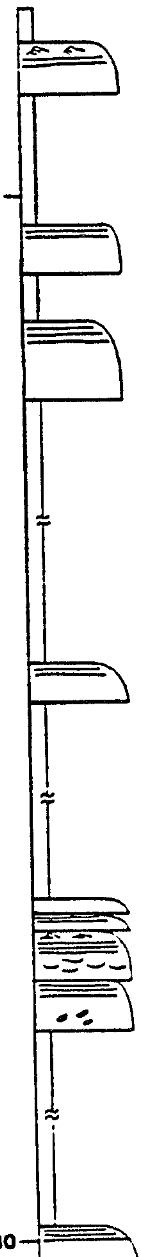
GATES CANYON SECS. 11, 12, T.6N., R.2W.

THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



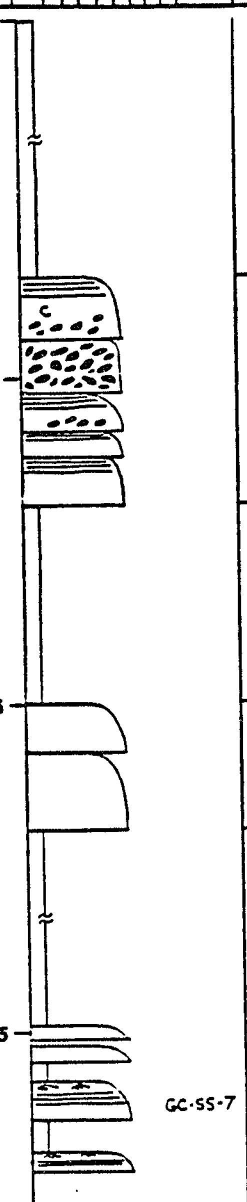
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
CHANNEL MARGIN	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar, poorly exposed	B	ab
INTERCHANNEL?	Covered interval - 24 m		
CHANNEL	Sandstone; massive, planar, rippled	B	abc
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, concretionary	B	ab
	Sandstone; massive, planar	B	abc
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, shale rip-up clasts	B	ab
	Sandstone, massive, planar, shale rip-up clasts	B	ab
	Sandstone; massive, planar, rippled, flame structs.	B	abc
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar, shale rip-up clts, flame structures	B	abc
	Sandstone; massive, planar, rippled	B	abc
	Interbedded sandstone and shale; 9:1	E,G	cde
	Covered interval		
	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar	B	ab
	Covered interval		
	Sandstone; planar, rippled, poorly exposed	D	bc
	Sandstone; massive planar, convolute laminations	B	abc
	Sandstone; poorly exposed	B	?
INTERCHANNEL?	Covered interval - 66 m		

GATES CANYON SECS. 11, 12, T.6N., R.2W. PAGE 10 of 11



THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	CHANNEL	Covered interval		
	CHANNEL	Sandstone; massive, planar, rippled	B	abc
	CHANNEL	Covered interval		
970	CHANNEL	Sandstone; massive, planar	B	ab
	CHANNEL	Covered interval		
	CHANNEL	Sandstone; massive, planar	B	ab
	INTERCHANNEL ?	Covered interval -30 m		
	INTERCHANNEL ?	Sandstone; massive, planar	C	ab
	INTERCHANNEL ?	Covered interval - 8 m		
	INTERCHANNEL ?	Sandstone; poorly exposed	B	?
	CHANNEL MARGIN	Sandstone; massive planar poorly exposed	B	ab
	CHANNEL MARGIN	Sandstone; massive, planar, rippled, dewatering structures	B	abc
	CHANNEL MARGIN	Sandstone; massive, planar, small rip-up clasts	B	ab
	INTERCHANNEL ?	Covered interval - 46 m		
880		Sandstone; massive, planar	B	ab

GATES CANYON SECS. 11, 12, T.6N., R.2W. PAGE 11 of 11

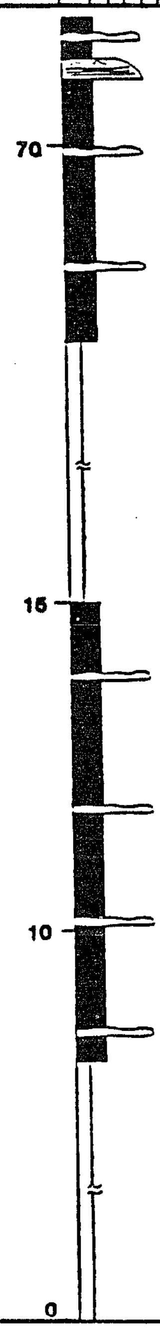


THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
1202	SLOPE?	Covered interval - 110 m		
	GULLY	Sandstone; massive, planar, shale rip-up clasts, concretionary	B	ab
	GULLY	Shale rip-up-clast conglomerate	A	a
1090	GULLY	Sandstone; massive, planar, shale rip-up clasts	B	ab
	GULLY	Sandstone; massive, planar	B	ab
	GULLY	Sandstone; massive, planar	B	ab
	SLOPE?	Covered interval		
1085	GULLY	Sandstone; massive, poorly exposed	B	a
	GULLY	Sandstone; massive, poorly exposed	B	a
	SLOPE?	Covered interval - 108 m		
	SLOPE?	Sandstone; poorly exposed	B	?
	SLOPE?	Covered interval		
975	CHANNEL	Sandstone; poorly exposed	B	?
	CHANNEL	Covered interval		
	CHANNEL	Sandstone, massive, planar, rippled	B	abc
	CHANNEL	Covered interval		
	CHANNEL	Sandstone; massive, planar, rippled	B	abc

C. MARSH CREEK MEASURED SECTION

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 1 of 18

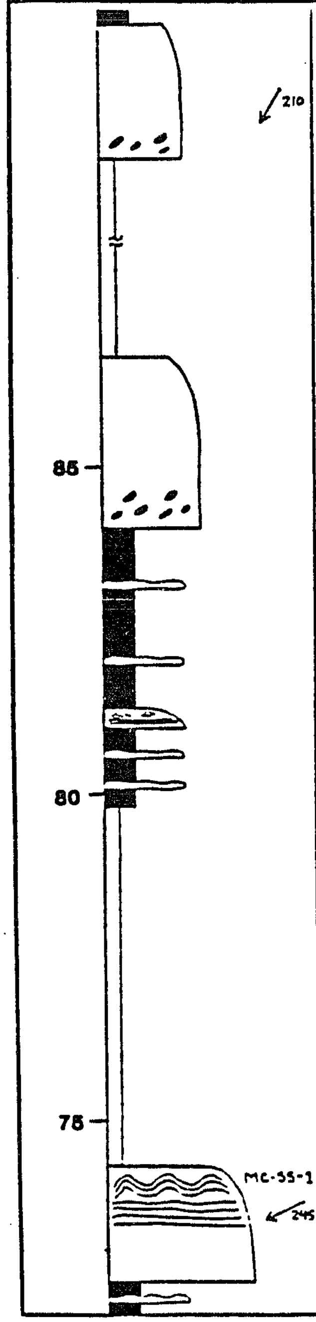
THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
FAN FRINGE	Interbedded sandstone and shale ; 1:3	D,G	c,d,e
FAN FRINGE	Sandstone ; planar, rippled	D	bce
FAN FRINGE	Interbedded sandstone and shale ; 1:9	D,G	c,d,e
BASIN PLAIN	Covered interval - 52 m		
BASIN PLAIN	Interbedded sandstone and shale ; 1:9	D,G	c,d,e
BASIN PLAIN	Covered interval - 8 m		

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 2 of 18

THICKNESS (meters) | GRAIN SIZE C S VF M C VG P

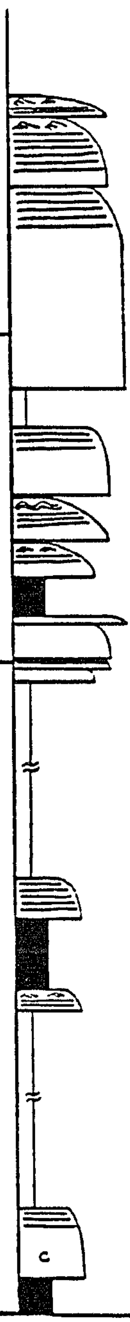


FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
FAN FRINGE	Sandstone; massive, shale rip-up clasts	C	a
	Covered interval - 9m		
	Sandstone; massive, shale rip-up clasts	C	a
	Interbedded sandstone and shale; 1:7	D,G	c,d,e
	Sandstone; planar, rippled	D	bce
	Interbedded sandstone and shale; 1:3	D.G	c,d,e
	Covered interval		
	Sandstone; massive, planar, convolute laminations	C	abc

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 3 of 18

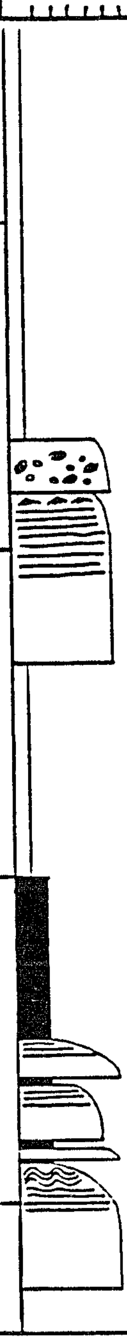
GRAIN SIZE

C S VF M C VG P



THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		Sandstone; planar, rippled	D	bce
	LOBE 1	Sandstone; planar, rippled	D	bc
140	LOBE 1	Sandstone; massive, planar	C	ab
	LOBE 1	Covered interval		
	LOBE 1	Sandstone; massive, planar, poorly exposed	C	ab
	LOBE 1	Sandstone; massive, planar, convolute laminations	C	abce
	LOBE 1	Sandstone; massive, planar, rippled	C	abce
	LOBE 1	Shale	G	e
	LOBE 1	Sandstone; massive	C	a
	LOBE 1	Sandstone; massive	C	a
	LOBE 1	Sandstone; massive, planar	C	ab
135	LOBE 1	Sandstone; massive	C	a
	FAN FRINGE	Covered interval - 25 m		
	FAN FRINGE	Sandstone; planar	D	b
	FAN FRINGE	Shale	G	e
	FAN FRINGE	Sandstone; planar, rippled	D	bce
	FAN FRINGE	Covered interval - 8m		
	FAN FRINGE	Sandstone; massive, planar, concretionary	C	ab
	FAN FRINGE	Shale	G	e

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 4 of 18



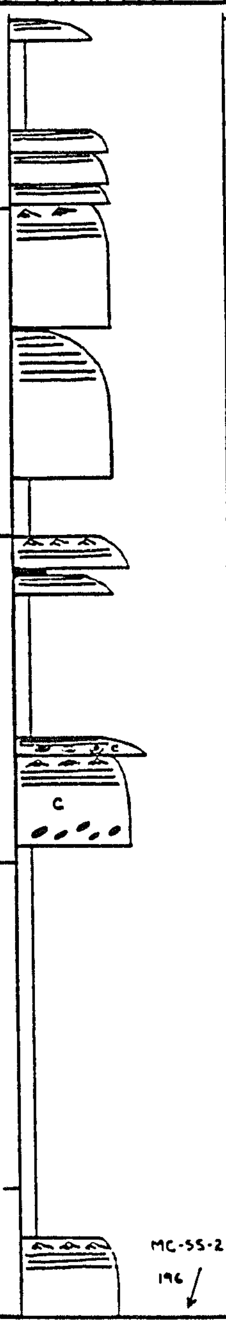
THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
160	INTERLOBE	Covered interval		
	LOBE 2	Sandstone; pebbles, shell fragments	C	a
155	LOBE 2	Sandstone; planar, rippled	C	abc
	LOBE 2	Covered interval		
150	LOBE 2	Shale	G	e
	LOBE 1	Sandstone; massive, planar	C	abe
	LOBE 1	Shale	G	e
	LOBE 1	Sandstone; massive, planar	C	ade
	LOBE 1	Shale	G	e
	LOBE 1	Sandstone; massive, poorly exposed	C	a
145	LOBE 1	Sandstone; massive, planar, convolute laminations	C	abce

GRAIN SIZE
C S VF M C VG P

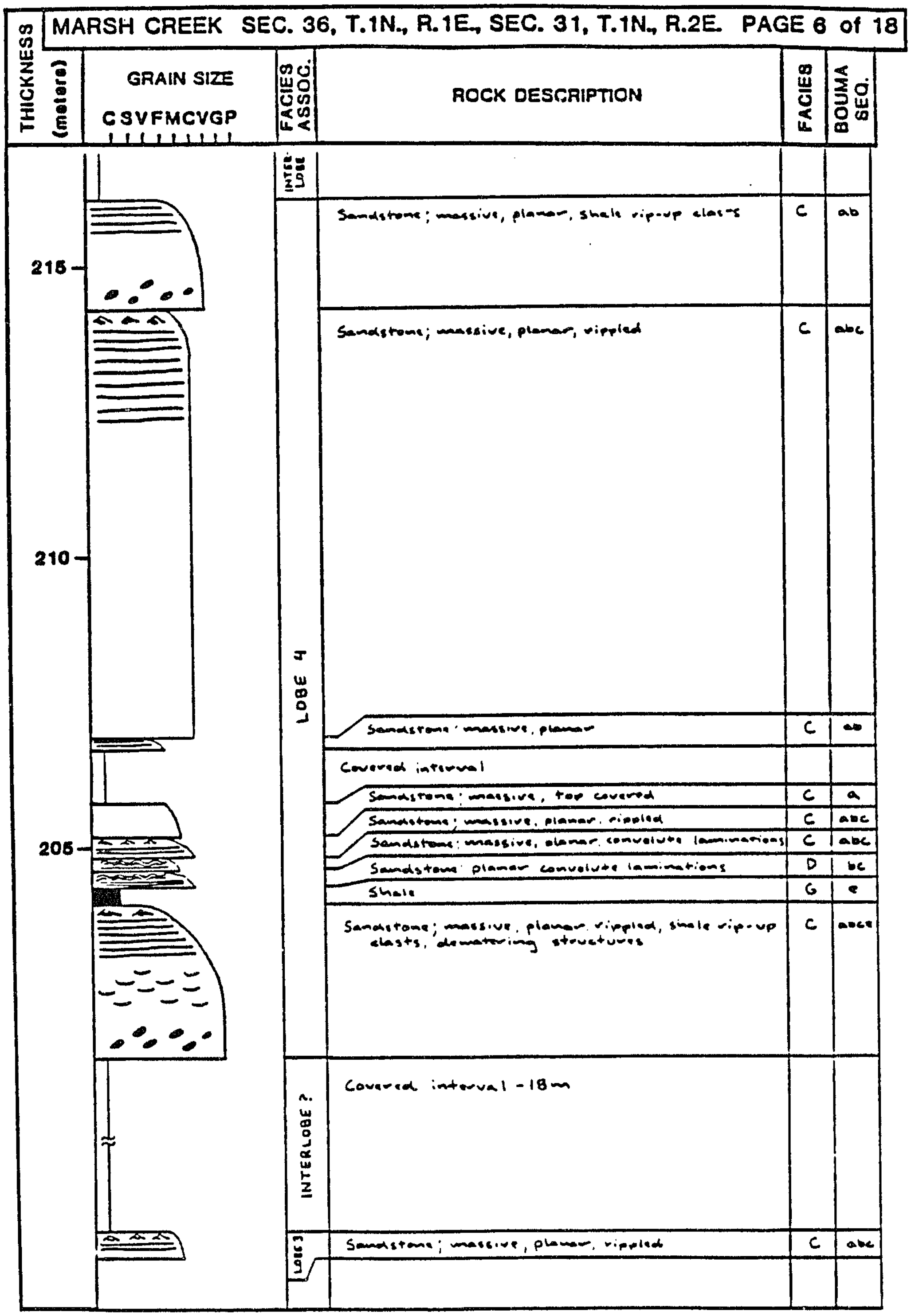
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 5 of 18

GRAIN SIZE

C S VF M C VG P

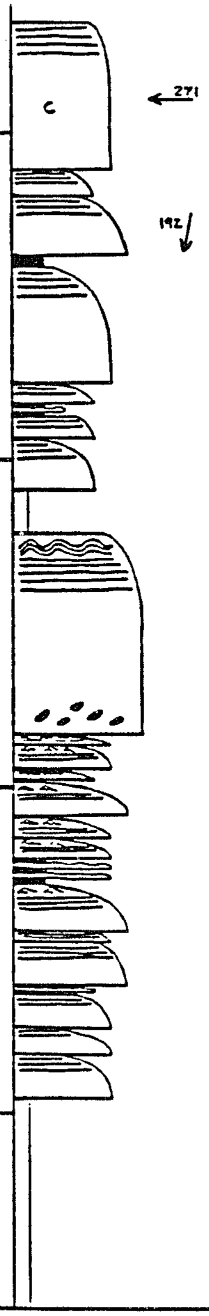


THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	LOBE 3	Sandstone; massive, planar	C	abc
	LOBE 3	Covered interval		
	LOBE 3	Sandstone; massive, planar	C	ab
	LOBE 3	Sandstone; massive, planar	C	ab
	LOBE 3	Sandstone; massive, planar	C	ab
180	LOBE 3	Sandstone; massive, planar, rippled	C	abc
	LOBE 3	Sandstone; massive, planar	C	abc
	LOBE 3	Covered interval		
175	LOBE 3	Sandstone; massive, planar, rippled	C	abc
	LOBE 3	Shale	G	e
	LOBE 3	Sandstone; massive, planar	C	abc
	LOBE 3	Covered interval		
	LOBE 3	Sandstone; massive, planar, small frags., convolutionary	C	ab
	LOBE 3	Sandstone; massive, planar, rippled, shale rip-up clasts, convolutionary	C	abc
170	INTERLOBE	Covered interval		
165	INTERLOBE			
	INTERLOBE	Sandstone; massive, planar, rippled	C	abc


MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 6 of 18
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
215
210
205
INTER-LOBE
LOBE 4
INTERLOBE ?
LOBE 3
Sandstone; massive, planar, shale rip-up clasts
C
ab
Sandstone; massive, planar, rippled
C
abc
Sandstone; massive, planar
C
ab
Covered interval
Sandstone; massive, top covered
C
a
Sandstone; massive, planar, rippled
C
abc
Sandstone; massive, planar, convolute laminations
C
abc
Sandstone; planar, convolute laminations
D
bc
Shale
G
e
Sandstone; massive, planar, rippled, shale rip-up clasts, dewatering structures
C
abce
Covered interval - 18m
Sandstone; massive, planar, rippled
C
abc

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 7 of 18

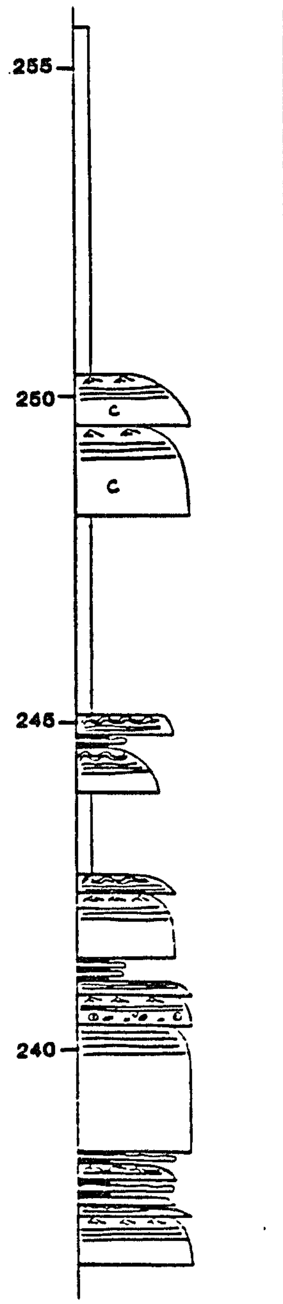
GRAIN SIZE
C S VF M C VG P



THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
235	LOBE 6	Sandstone; massive, planar, "eye ball" concretion	C	ab
	LOBE 6	Sandstone: massive planar	C	ab
	LOBE 6	Sandstone; massive, planar	C	ab
	LOBE 6	Shale	G	e
	LOBE 6	Sandstone; massive, planar	C	abe
	LOBE 6	Sandstone; massive, planar	C	abe
	LOBE 6	Interbedded siltstone and shale; 1:1	D, G	c, d, e
	LOBE 6	Sandstone; massive, planar	C	abe
230	LOBE 6	Sandstone; massive, planar	C	abe
	LOBE 6	Covered interval		
	LOBE 5	Sandstone; massive, planar, convolute laminations, shale rip-up clasts	C	abe
	LOBE 5	Sandstone; massive, planar, rippled	C	abc
	LOBE 5	Sandstone; massive, planar, rippled	C	abc
	LOBE 5	Sandstone; massive, planar	C	abe
225	LOBE 5	Sandstone: massive planar rippled	C	abce
	LOBE 5	Sandstone; planar, rippled	D	bce
	LOBE 5	Sandstone; massive, planar, rippled	C	abc
	LOBE 5	Interbedded sandstone and shale; 1:1	D, G	c, a, e
	LOBE 5	Sandstone; massive, planar, rippled	C	abce
	LOBE 5	Sandstone; massive, planar	C	ab
	LOBE 5	Sandstone: massive, planar	C	ab
	LOBE 5	Interbedded sandstone and shale; 1:5	D, G	c, d, e
	LOBE 5	Sandstone; massive, planar	C	abe
	LOBE 5	Sandstone; massive, planar	C	ab
	LOBE 5	Sandstone; massive, planar	C	ab
220	INTERLOBE	Covered interval		

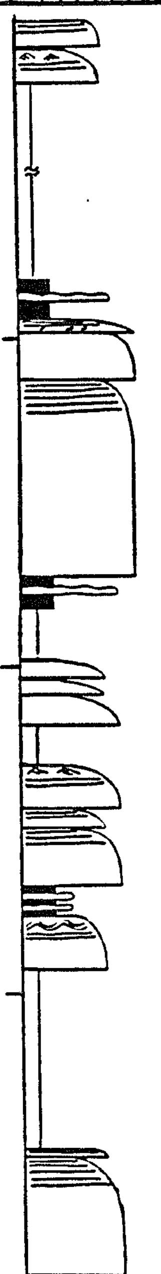
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 8 of 18

THICKNESS (meters) | GRAIN SIZE C S VF F M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
LOBE 7	Covered interval		
LOBE 7	Sandstone; massive, planar, rippled, convolutionary	C	abc
LOBE 7	Sandstone; massive, planar, rippled, convolutionary	C	abc
LOBE 7	Covered interval		
LOBE 7	Sandstone; massive, planar, convolute laminations	C	abc
LOBE 7	Interbedded siltstone and shale; 1:1	D,G	c,d,e
LOBE 7	Sandstone; massive, planar, convolute laminations	C	abce
LOBE 7	Covered interval		
LOBE 7	Sandstone; massive, planar, convolute laminations	C	abc
LOBE 6	Sandstone; massive, planar, rippled	C	abc
LOBE 6	Interbedded siltstone and shale; 1:1	D,G	c,d,e
LOBE 6	Sandstone, massive, planar	C	abe
LOBE 6	Sandstone; massive, planar, rippled, shale ripup clasts, convolutionary clasts	C	abc
LOBE 6	Sandstone; massive, planar	C	ab
LOBE 6	Interbedded sandstone and shale; 5:1	D,G	c,d,e
LOBE 6	Sandstone; massive, planar, rippled	C	abce
LOBE 6	Interbedded sandstone and shale; 5:1	D,G	c,d,e
LOBE 6	Sandstone; massive	C	a
LOBE 6	Sandstone; massive, planar, convolute laminations	C	abc
LOBE 6	Sandstone; massive, planar, rippled	C	abc

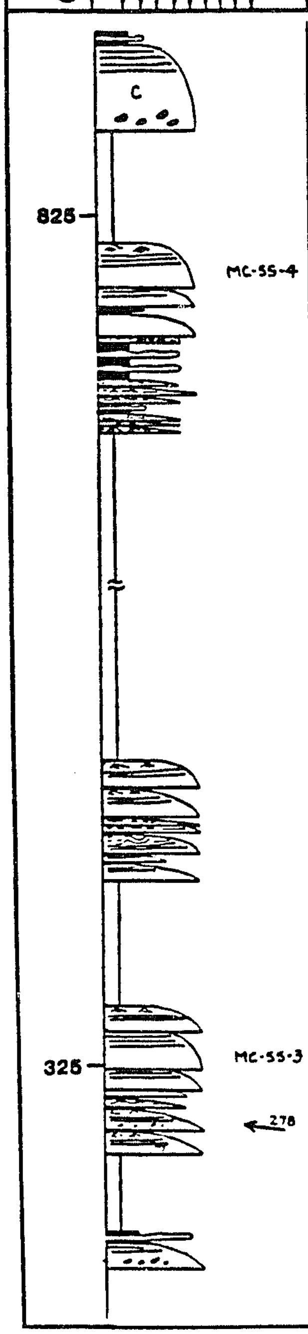
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 9 of 18



THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	LOBE 9	Sandstone; massive, planar	C	ab
	LOBE 9	Sandstone; massive, planar, rippled	C	abce
	INTERLOBE ?	Covered interval - 51 m		
	INTERLOBE ?	Interbedded sandstone and shale; 1:3	D,G	c,d,e
	LOBE 8	Sandstone; massive, planar, shale rip-up clasts	C	abe
270	LOBE 8	Sandstone; massive	C	a
	LOBE 8	Sandstone; massive, planar	C	ab
	LOBE 8	Interbedded sandstone and shale; 1:3	D,G	c,d,e
	LOBE 8	Covered interval		
	LOBE 8	Sandstone; poorly exposed	C?	?
265	LOBE 8	Sandstone; poorly exposed	C?	?
	LOBE 8	Sandstone; poorly exposed	C?	?
	LOBE 8	Covered interval		
	LOBE 8	Sandstone; massive, planar, rippled	C	abc
	LOBE 8	Sandstone; massive, planar,	C	ab
	LOBE 8	Sandstone; massive, planar	C	ab
	LOBE 8	Interbedded siltstone and shale; 1:1	D,G	c,d,e
	LOBE 8	Sandstone; massive, planar, convolute laminations	C	abce
260	LOBE 8	Covered interval		
	LOBE 8	Sandstone, massive, planar	C	ab
	LOBE 7	Sandstone; massive, planar	C	ab

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 10 of 18

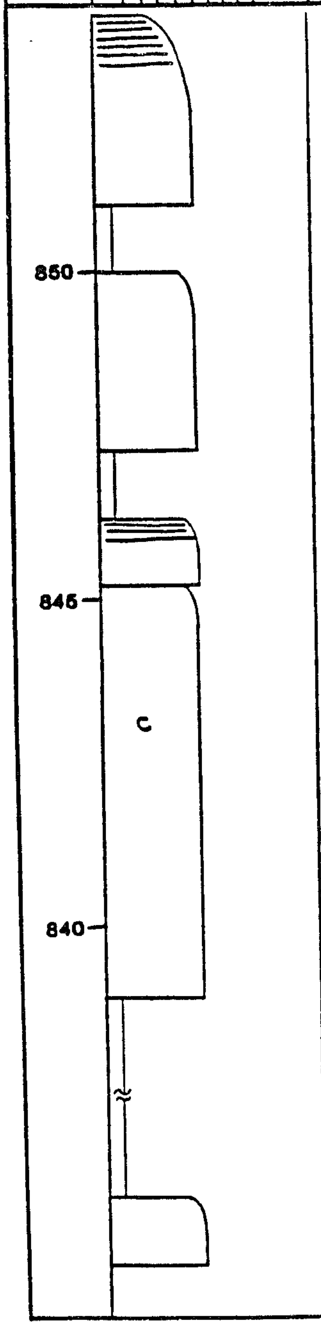
THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Interbedded siltstone and shale; 1:3	E,G	c,d,e
LEVEE	Sandstone; massive, planar, shale ripup clasts, concretionary	B	abe
LEVEE	Covered interval		
LEVEE	Sandstone; massive, planar, rippled	B	abc
LEVEE	Sandstone; massive, planar	B	ab
LEVEE	Interbedded siltstone and shale; 1:9	E,G	c,d,e
LEVEE	Sandstone; massive	B	a
LEVEE	Sandstone; planar, rippled	D	bc
LEVEE	Interbedded sandstone and shale; 3:1	E,G	c,d,e
LEVEE	Sandstone; planar, rippled	D	bce
LEVEE	Sandstone, planar, rippled	D	bce
LEVEE	Sandstone; planar, rippled	D	bc
LEVEE	Interbedded siltstone and shale; 1:3	E,G	c,d,e
LEVEE	Sandstone; planar, rippled	D	bce
LEVEE	Sandstone; planar, rippled	D	bc
LEVEE	Sandstone; planar, rippled	D	bc
OUTER FAN - MIDDLE FAN TRANSITION?	Covered interval - 492 m		
OUTER FAN - MIDDLE FAN TRANSITION?	Sandstone; massive, planar rippled	C	abc
LOBE 9	Sandstone; massive, planar, rippled	C	abce
LOBE 9	Sandstone; massive, planar, rippled	C	abce
LOBE 9	Sandstone; massive, planar, rippled	C	abc
LOBE 9	Sandstone; massive, planar, convolute laminations	C	abce
LOBE 9	Sandstone; massive, planar	C	abe
LOBE 9	Sandstone; massive, planar	C	abe
LOBE 9	Covered interval		
LOBE 9	Sandstone; massive, planar, rippled	C	abc
LOBE 9	Sandstone; massive, planar	C	ab
LOBE 9	Sandstone, massive, planar	C	ab
LOBE 9	Sandstone, poorly exposed	C?	?
LOBE 9	Sandstone; massive, planar, rippled	C	abce
LOBE 9	Sandstone; massive, planar, rippled, shale ripup clsts.	C	abce
LOBE 9	Sandstone; massive, planar, rippled, burrowed	C	abce
LOBE 9	Covered interval		
LOBE 9	Interbedded sandstone and shale; 1:1	D,G	c,d,e
LOBE 9	Sandstone; massive, planar, shale ripup clasts	C	abe

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 11 of 18

THICKNESS (meters) | GRAIN SIZE C S VF M C VG P



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
CHANNEL	Covered interval		
CHANNEL	Sandstone; poorly exposed	B?	?
CHANNEL	Covered interval		
CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab
CHANNEL	Sandstone; convolutionary, poorly exposed	B?	?
INTERCHANNEL?	Covered interval – 10 m		
LEVEE	Sandstone; poorly exposed	B?	?

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 12 of 18

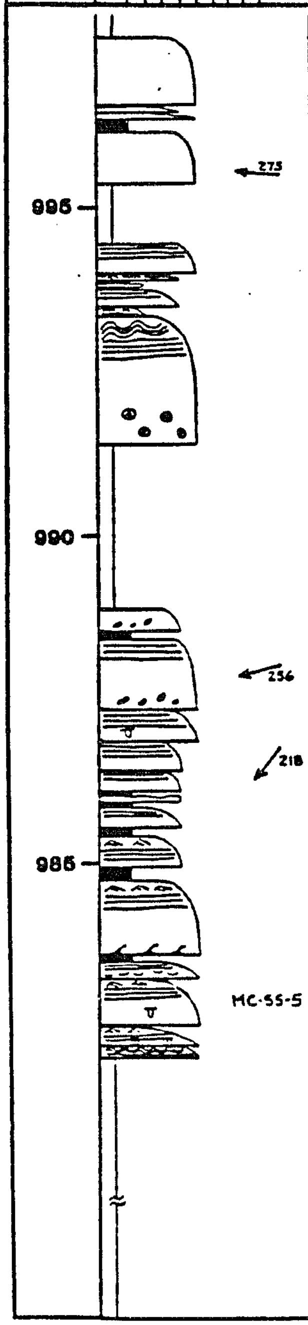
THICKNESS (meters)	GRAIN SIZE C S VF F M C VG P	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		CHANNEL MARGIN	Sandstone; massive, planar	B	ab
		CHANNEL MARGIN	Sandstone; massive, planar, rippled, shale rip-up clasts	B	abc
970		CHANNEL MARGIN	Sandstone; massive, planar, rippled, burrowed	B	abc
		INTERCHANNEL ?	Covered interval -105 m		
	C	CHANNEL	Sandstone; massive, planar, concretionary	B	ab
860		CHANNEL	Covered interval		
855		CHANNEL	Sandstone; massive, planar, poorly exposed	B	ab

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 13 of 18

THICKNESS (meters)

GRAIN SIZE

C S VF M C VG P

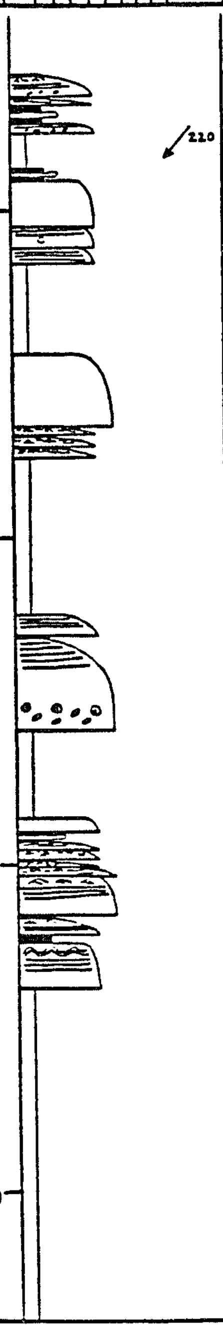


FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
	Sandstone; massive	B	a
CHANNEL MARGIN	Sandstone; poorly exposed	?	?
CHANNEL MARGIN	Sandstone; poorly exposed	?	?
CHANNEL MARGIN	Shale	G	e
CHANNEL MARGIN	Sandstone; poorly exposed	B?	?
CHANNEL MARGIN	Covered interval		
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
CHANNEL MARGIN	Sandstone; massive, planar, rippled	B	abc
CHANNEL MARGIN	Interbedded siltstone and shale; 3:1	E,G	cde
CHANNEL MARGIN	Sandstone; massive, planar	B	abe
CHANNEL MARGIN	Siltstone; planar, rippled	D	bc
CHANNEL MARGIN	Sandstone; massive, planar, convolute laminations, concretionary clasts	B	abc
CHANNEL MARGIN / LEVEE	Covered interval		
CHANNEL MARGIN / LEVEE	Sandstone; massive, shale rip-up clasts	B	a
CHANNEL MARGIN / LEVEE	Shale	G	e
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar, shale rip-up clasts	B	ab
CHANNEL MARGIN / LEVEE	Sandstone; planar, burrowed	D	b
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar	B	ab
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar	B	ab
CHANNEL MARGIN / LEVEE	Interbedded sandstone and shale; 3:1	E,G	cde
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar	B	abe
CHANNEL MARGIN / LEVEE	Shale	G	e
CHANNEL MARGIN / LEVEE	Sandstone; planar, rippled	D	bc
CHANNEL MARGIN / LEVEE	Shale	G	e
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar, rippled, flame structures	B	abce
CHANNEL MARGIN / LEVEE	Shale	G	e
CHANNEL MARGIN / LEVEE	Sandstone, planar dewatering structures	D	be
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar, rippled, burrowed	B	abc
CHANNEL MARGIN / LEVEE	Sandstone; planar, rippled, concretionary clsts.	D	bce
CHANNEL MARGIN / LEVEE	Sandstone; massive, planar, convolute laminations	B	abc
INTERCHANNEL ?	Covered interval - 8.5 m		

MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 14 of 18

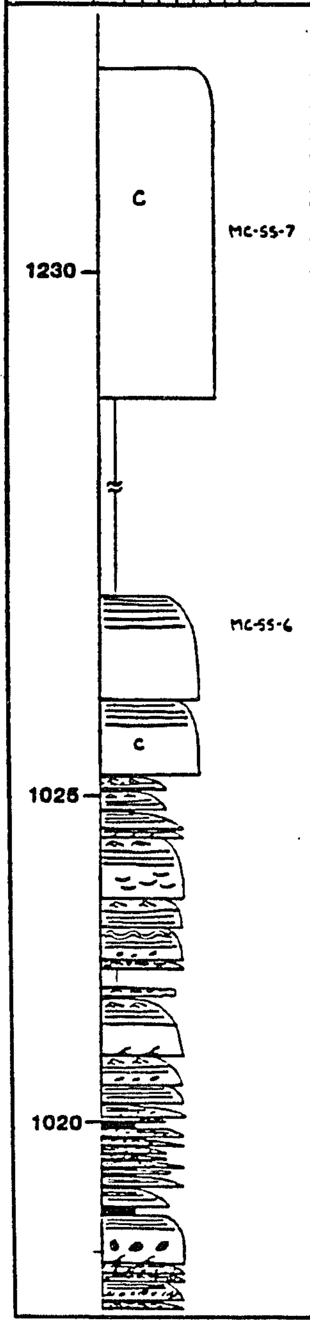
THICKNESS (meters)

GRAIN SIZE
C S VF M C VG P

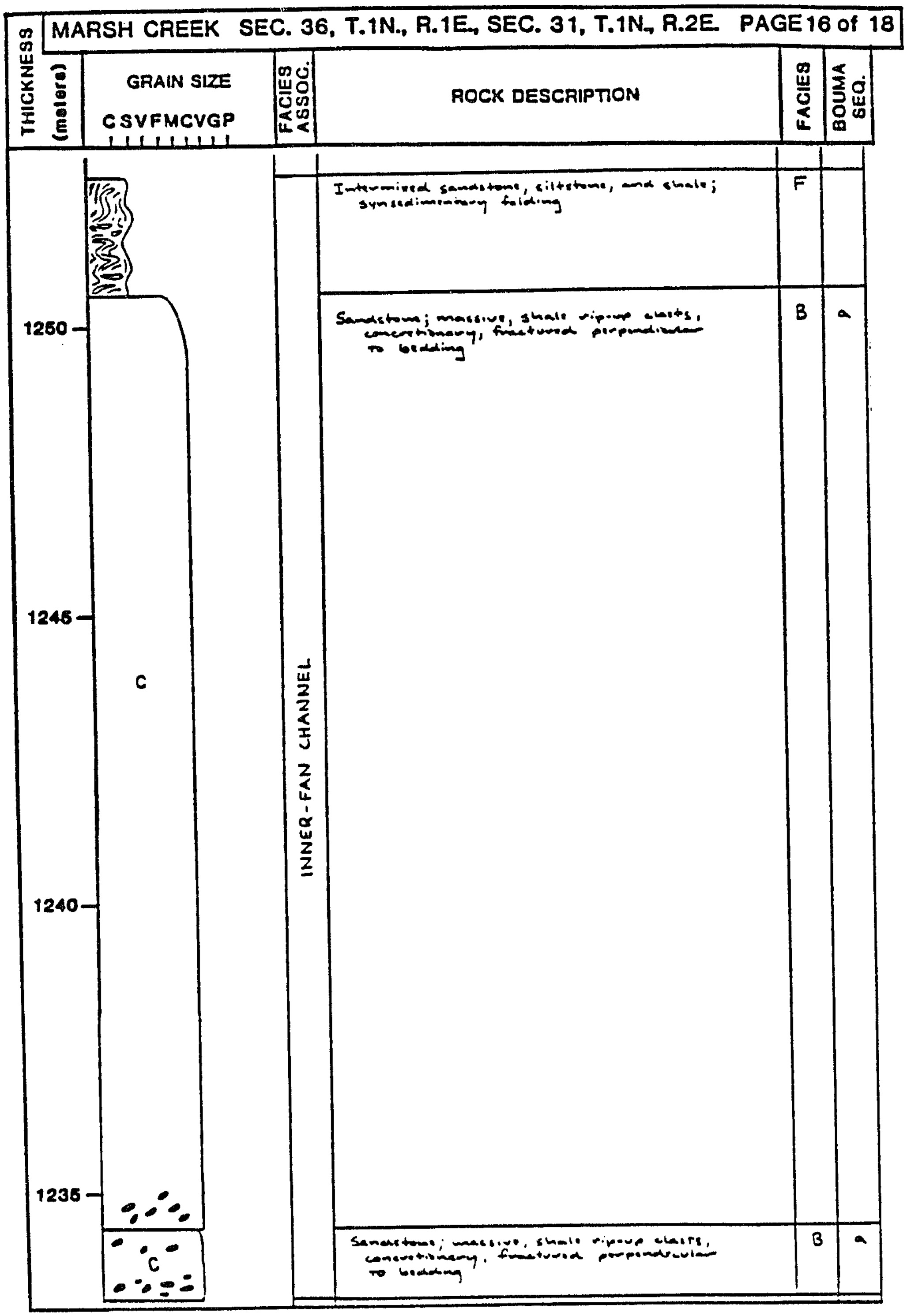


THICKNESS (meters)	FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
		Sandstone; massive, planar, rippled, shale rip-up clasts	B	abce
		Sandstone; planar	D	be
	CHANNEL MARGIN	Interbedded siltstone and shale; 1:5	E,G	c,d,e
	CHANNEL MARGIN	Sandstone; massive planar, shale rip-up clasts,	B	abe
	CHANNEL MARGIN	Covered interval		
	CHANNEL MARGIN	Interbedded siltstone and shale; 1:5	E,G	c,d,e
	CHANNEL MARGIN	Sandstone; massive	B	a
1015	CHANNEL MARGIN	Sandstone; massive, planar, concretionary	B	ab
	CHANNEL MARGIN	Sandstone; planar	D	b
	CHANNEL MARGIN	Covered interval		
	CHANNEL MARGIN	Sandstone; massive	B	a
	CHANNEL MARGIN	Sandstone; planar, rippled	D	bc
	CHANNEL MARGIN	Sandstone; planar, rippled	D	bce
	LEVEE	Sandstone; planar rippled	D	bce
1010	LEVEE	Covered interval		
	LEVEE	Sandstone; planar	D	b
	LEVEE	Sandstone; massive, planar, shale rip-up clasts, concretionary clasts	B	abe
	LEVEE	Covered interval		
	LEVEE	Sandstone: poorly exposed	?	?
	LEVEE	Interbedded siltstone and shale; 3:1	E,G	c,d,e
	LEVEE	Sandstone; planar	D	be
	LEVEE	Sandstone: planar, rippled, burrowed	D	bce
	LEVEE	Sandstone: planar, rippled	D	bce
	LEVEE	Sandstone: massive, planar, rippled	B	abc
1005	LEVEE	Sandstone; massive, planar, rippled	B	abc
	LEVEE	Sandstone: planar, rippled	D	bce
	LEVEE	Shale	G	e
	LEVEE	Sandstone; massive, planar, convolute laminations	B	abce
1000	INTERCHANNEL	Covered interval		

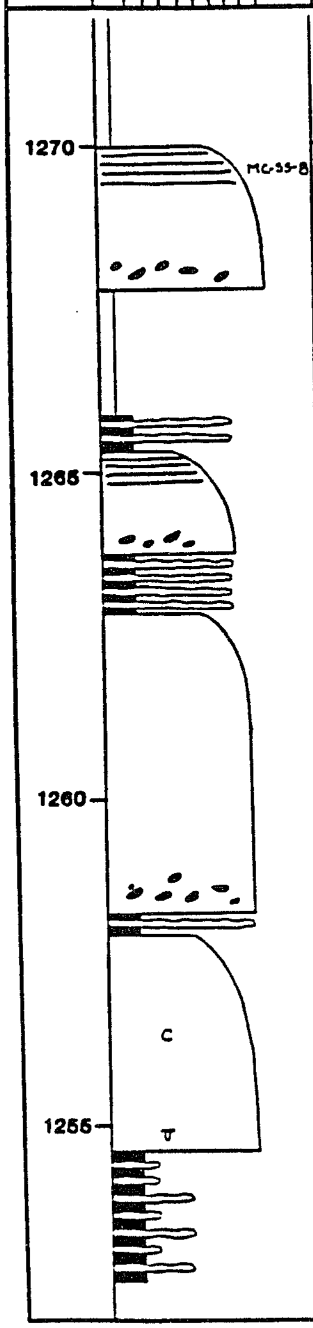
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 15 of 18



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
INNER-FAN CHANNEL	Sandstone; massive, concretionary, fractured perpendicular to bedding	B	a
MIDDLE FAN-INNER FAN TRANSITION?	Covered interval ~200 m		
CHANNEL MARGIN	Sandstone; massive, planar	B	ab
	Sandstone; massive, planar, concretionary	B	ab
	Sandstone; planar, rippled	D	bce
	Sandstone; planar, rippled	D	bce
	Sandstone; planar	D	be
	Sandstone; planar, flame structures	D	b
	Sandstone; massive, planar, rippled, dewatering str.	B	abc
	Sandstone; planar, rippled	D	bc
	Sandstone; massive, planar, convolute lams., shale rip-up clasts	B	abc
	Sandstone; planar, rippled	D	bc
	Covered interval		
	Sandstone; rippled, pinch and swell	E	c
	Sandstone; massive, planar, rippled, flame structures	B	abc
	Sandstone; massive, planar, rippled, shale ripup clsts.	B	abc
	Sandstone; planar	D	b
	Sandstone; planar, shale ripup clasts	D	be
	Sandstone; rippled, pinch and swell	E	c
	Shale	G	e
LEVEE	Sandstone; massive, planar, rippled, shale ripup clsts	B	abce
	Sandstone; planar, rippled, shale ripup clasts	D	bce
	Sandstone; planar, rippled, flame structures	D	bce
	Sandstone; rippled, pinch and swell, flame structures	E	c
	Sandstone; massive, planar, rippled	B	abce
	Interbedded sandstone and shale; 1:3	E, G	cde
	Sandstone; massive, planar	B	abe
	Sandstone; planar	D	be
	Shale	G	e
	Sandstone; massive, planar, shell frags., flame strs.	B	abe
CHANNEL MARGIN	Sandstone; planar, rippled, shale ripup clsts., shell fragments	D	bc
	Sandstone; planar, rippled, shale ripup clsts., shell fragments	D	bc
	Sandstone; planar, shale ripup clasts, shell fragments	D	b
	Sandstone; massive, planar, rippled, shale ripup clsts.	B	abce


MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 16 of 18
THICKNESS (meters)
GRAIN SIZE
C S VF M C VG P
FACIES ASSOC.
ROCK DESCRIPTION
FACIES
BOUMA SEQ.
1250
1245
1240
1235
C
C
INNER-FAN CHANNEL
Intermixed sandstone, siltstone, and shale; synsedimentary folding
F
Sandstone; massive, shale rip-up clasts, concretionary, fractured perpendicular to bedding
B
a
Sandstone; massive, shale rip-up clasts, concretionary, fractured perpendicular to bedding
B
a

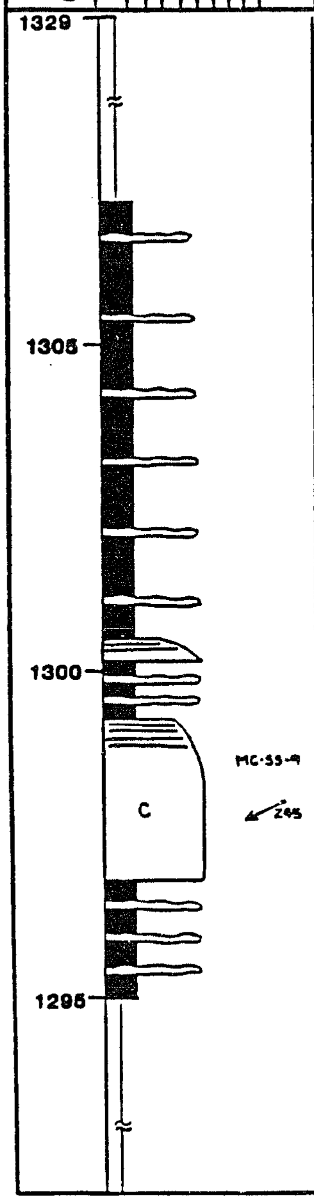
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 17 of 18



FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
INTERCHANNEL			
INNER-FAN CHANNEL	Sandstone; massive, planar, shale rip-up clasts	A	ab
	Covered interval		
	Interbedded sandstone and shale; 1:3	E,G	c,d,e
	Sandstone; massive, planar, shale rip-up clasts	B	ab
	Interbedded sandstone and shale; 5:1	E,G	c,d,e
	Sandstone; massive, shale rip-up clasts	B	a
	Interbedded sandstone and shale; 1:3	E,G	c,d,e
	Sandstone; massive, burrowed, concretionary	B	a
	Interbedded sandstone, siltstone, and shale; 1:3	E,G	c,d,e

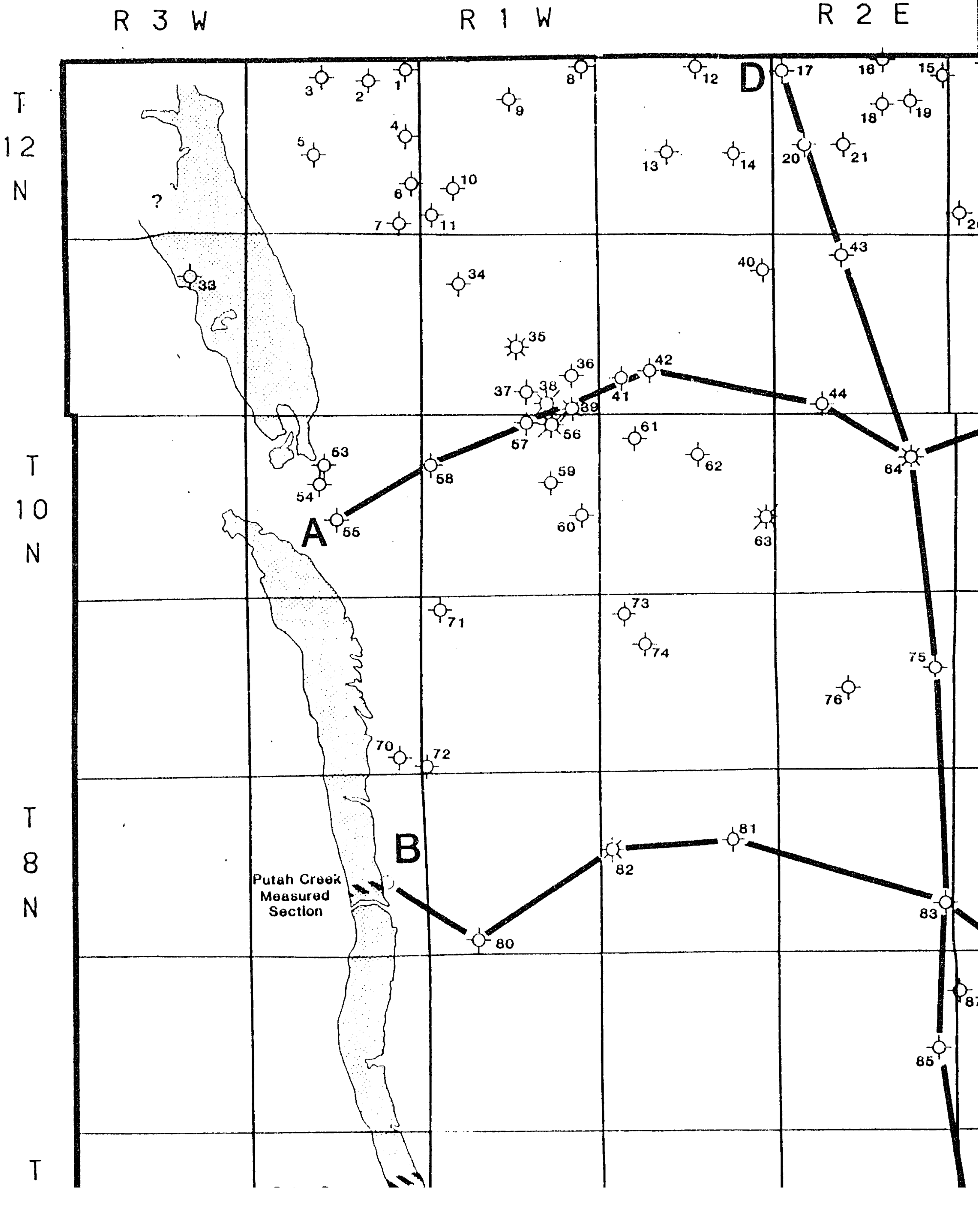
MARSH CREEK SEC. 36, T.1N., R.1E., SEC. 31, T.1N., R.2E. PAGE 18 of 18

THICKNESS (meters) | GRAIN SIZE C S VF M C VG P

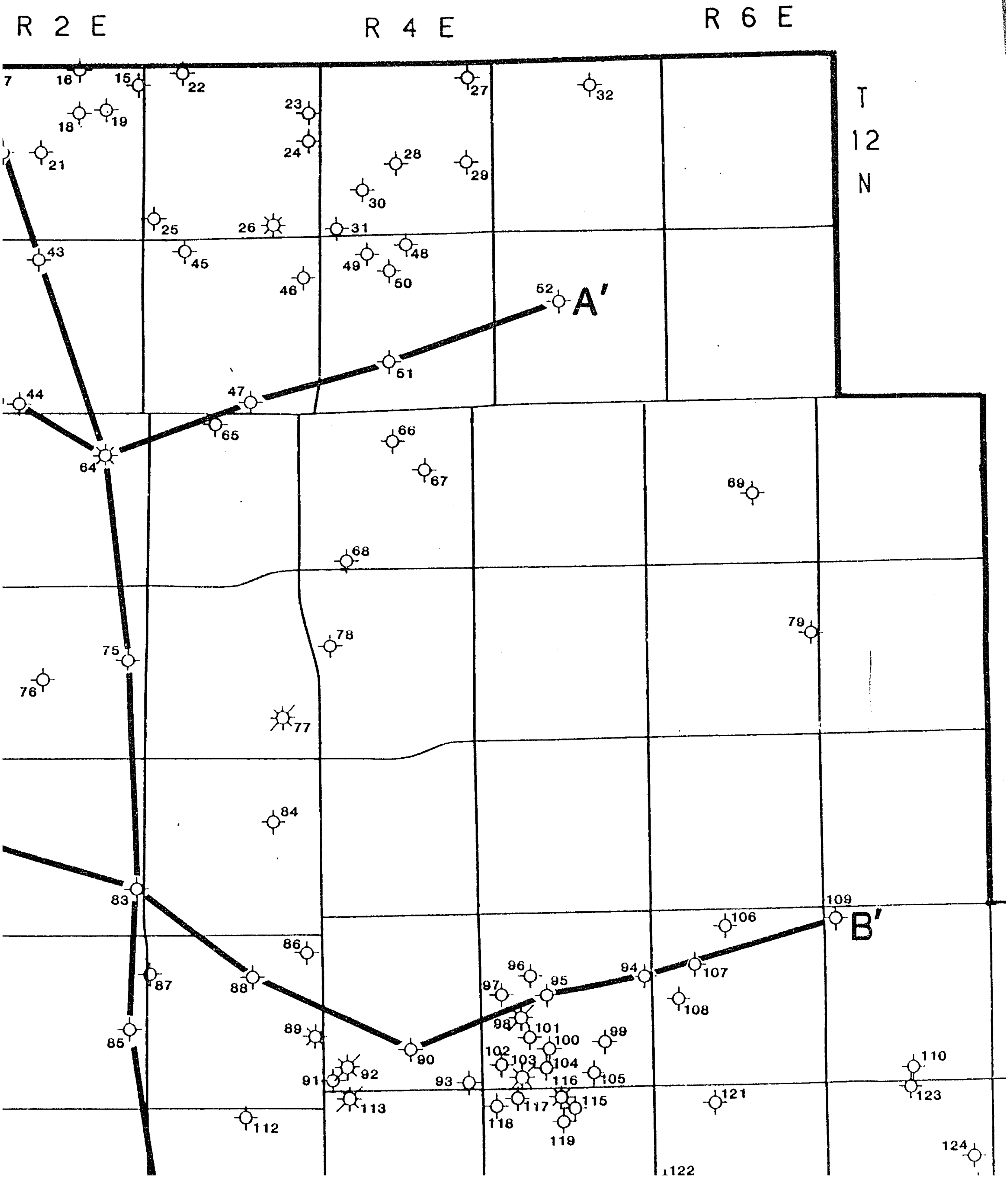


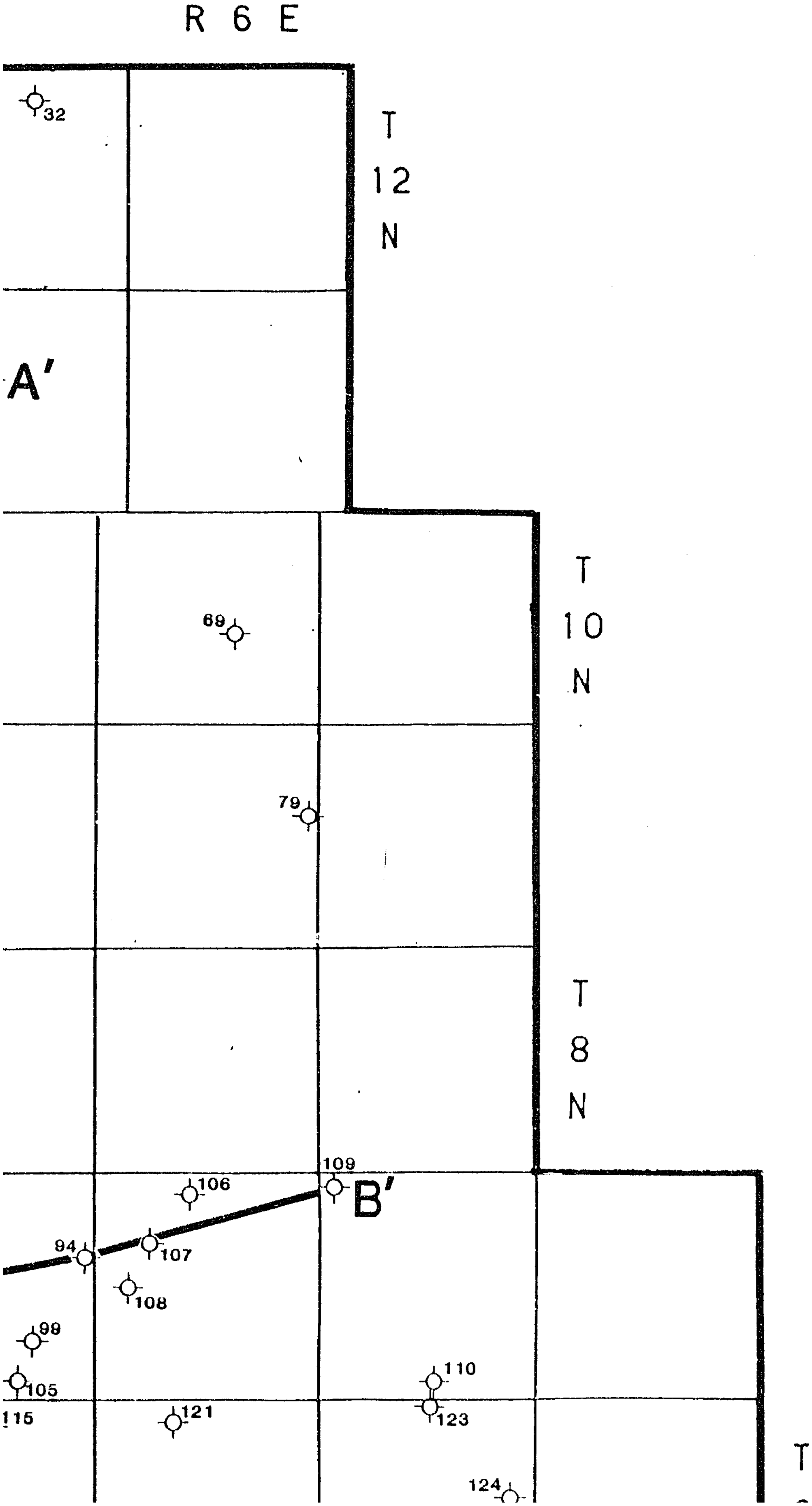
FACIES ASSOC.	ROCK DESCRIPTION	FACIES	BOUMA SEQ.
INTERCHANNEL?	Covered interval - 22 m		
LEVEE/INTERCHANNEL	Interbedded sandstone and shale; 1:7	E,G	c,d,e
	Sandstone; massive, planar	B	ab
INNER-FAN CHANNEL	Interbedded sandstone and shale; 1:1	E,G	c,d,e
	Sandstone; massive, planar, pinches out laterally into interchannel/levee facies associations, partially concretionary	B	ab
LEVEE	Interbedded sandstone and shale; 1:3	E,G	c,d,e
INTERCHANNEL?	Covered interval - 26 m		

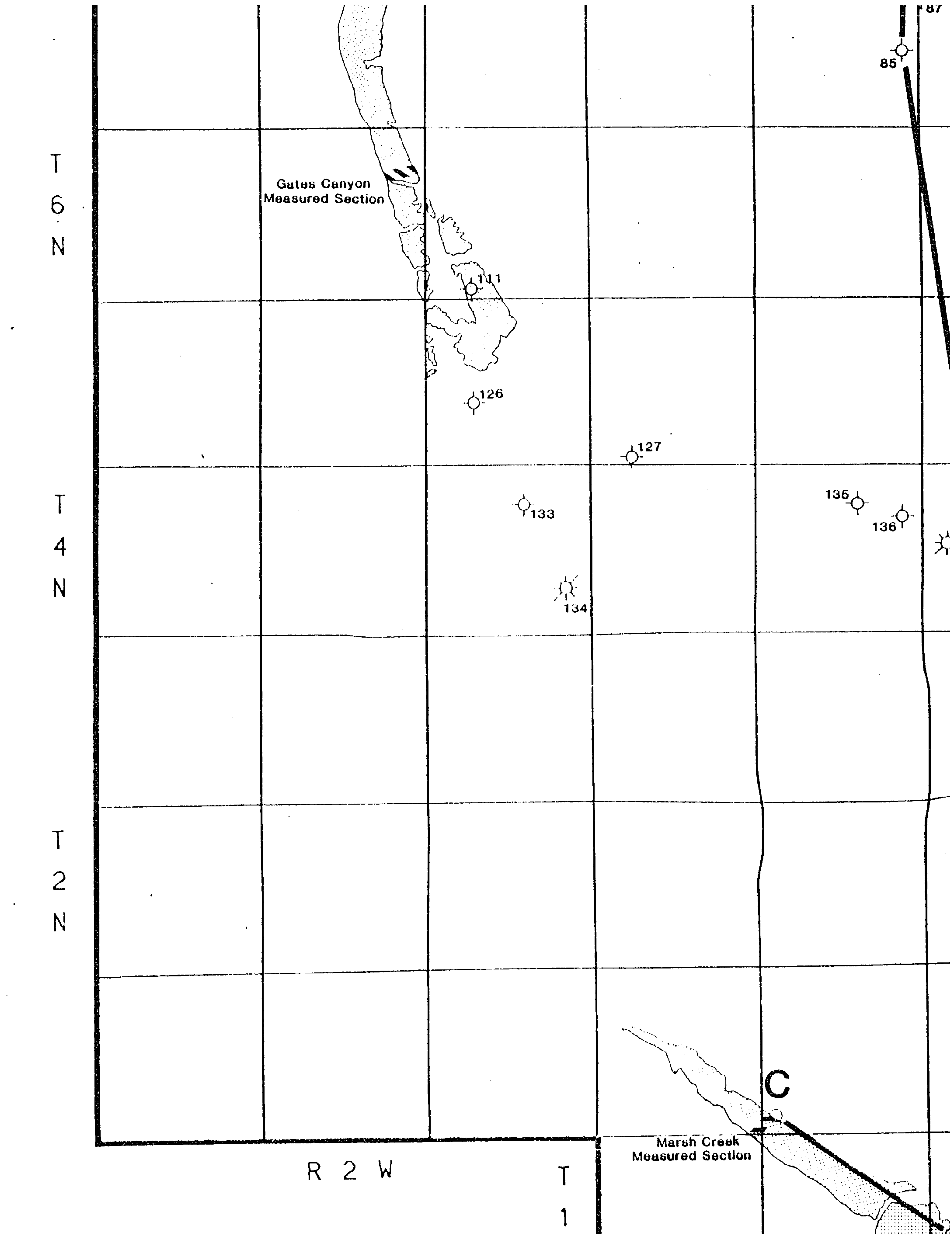
Base Map with Cros



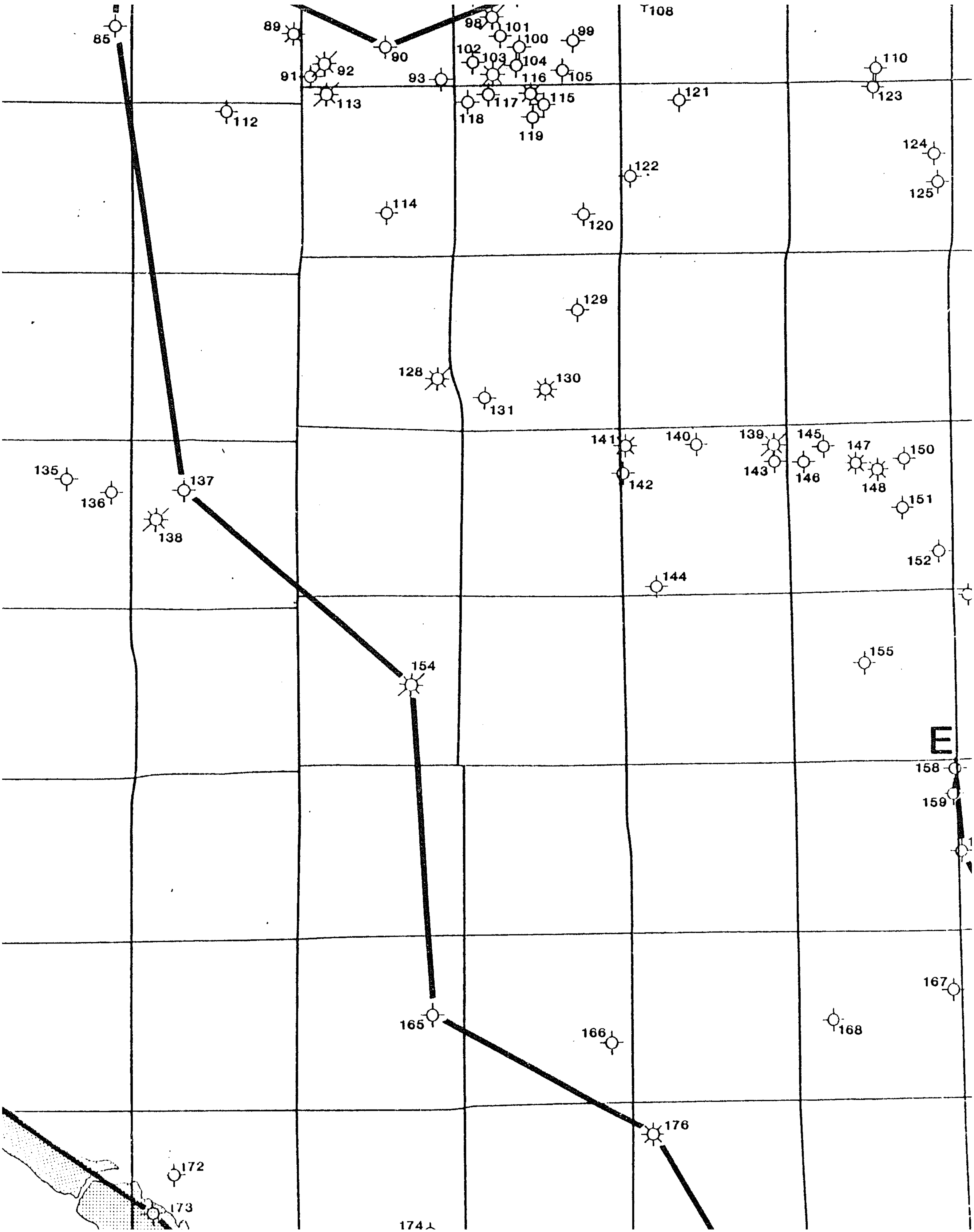
with Cross Sections



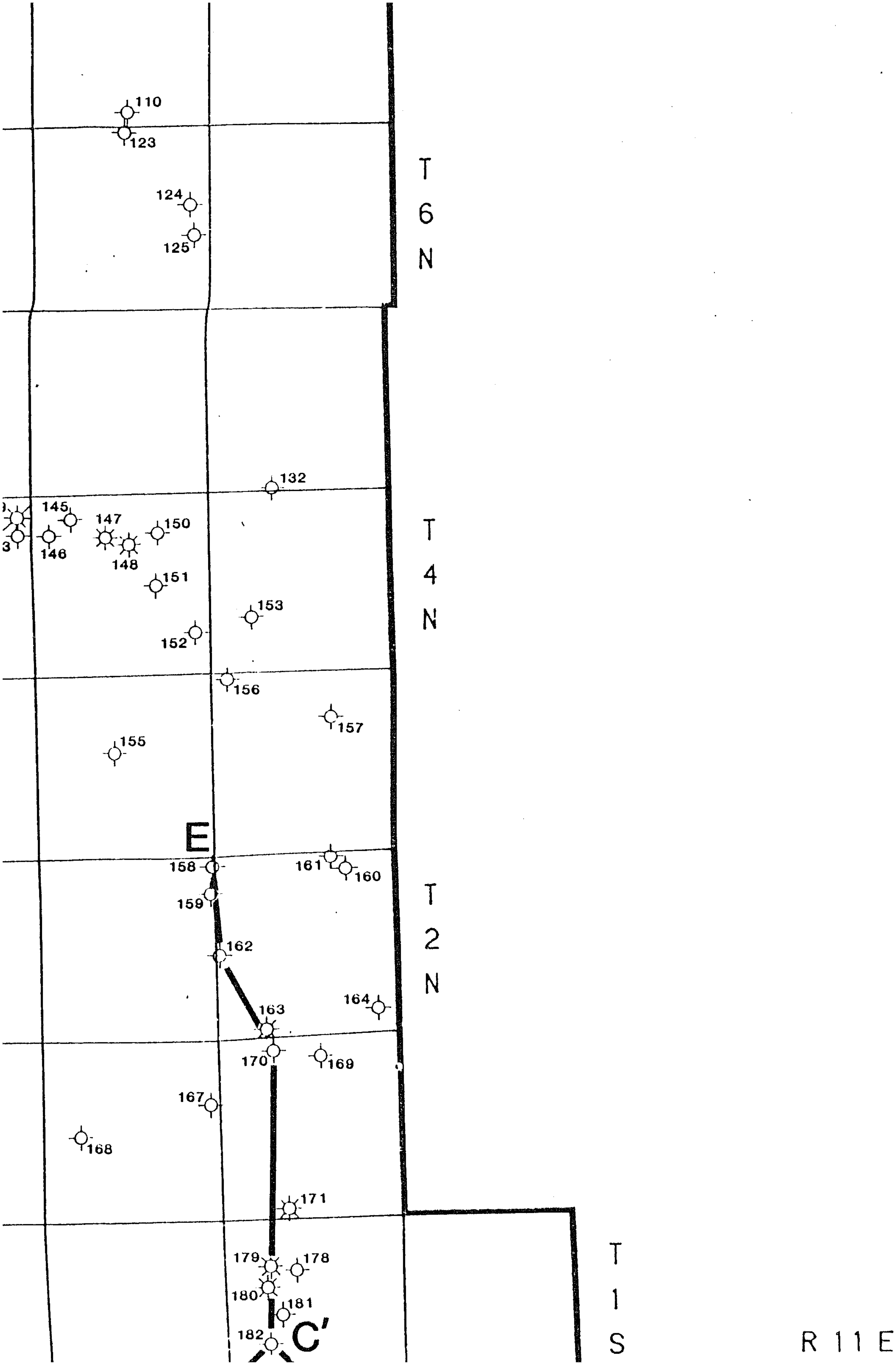

R 6 E
T 12 N
T 10 N
T 8 N
T
A'
B'
32
69
79
94
99
105
106
107
108
109
110
115
121
123
124

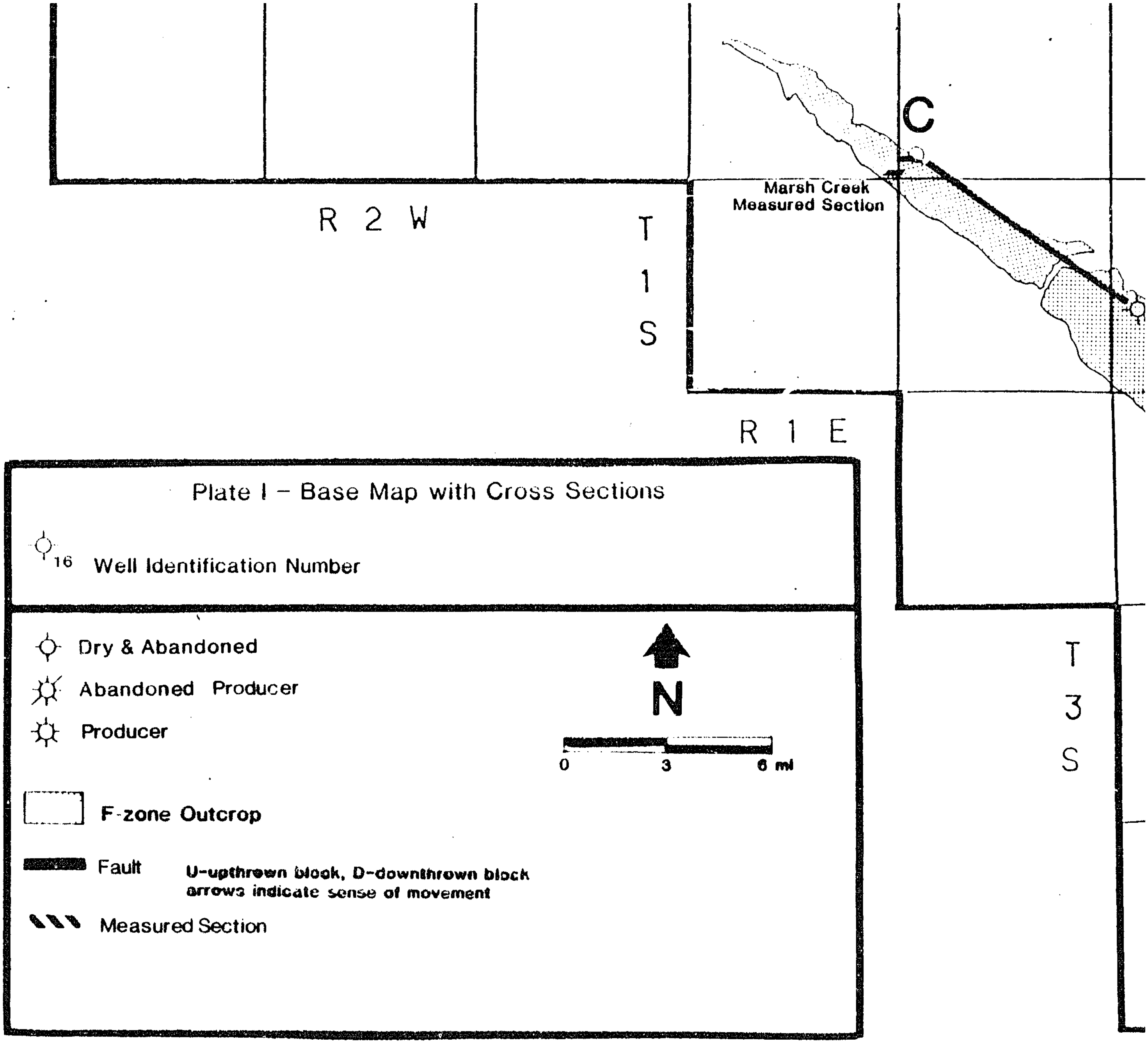


87
85
T 6 N
Gates Canyon Measured Section
111
126
127
T 4 N
133
135
136
134
T 2 N
C
Marsh Creek Measured Section
R 2 W
T 1

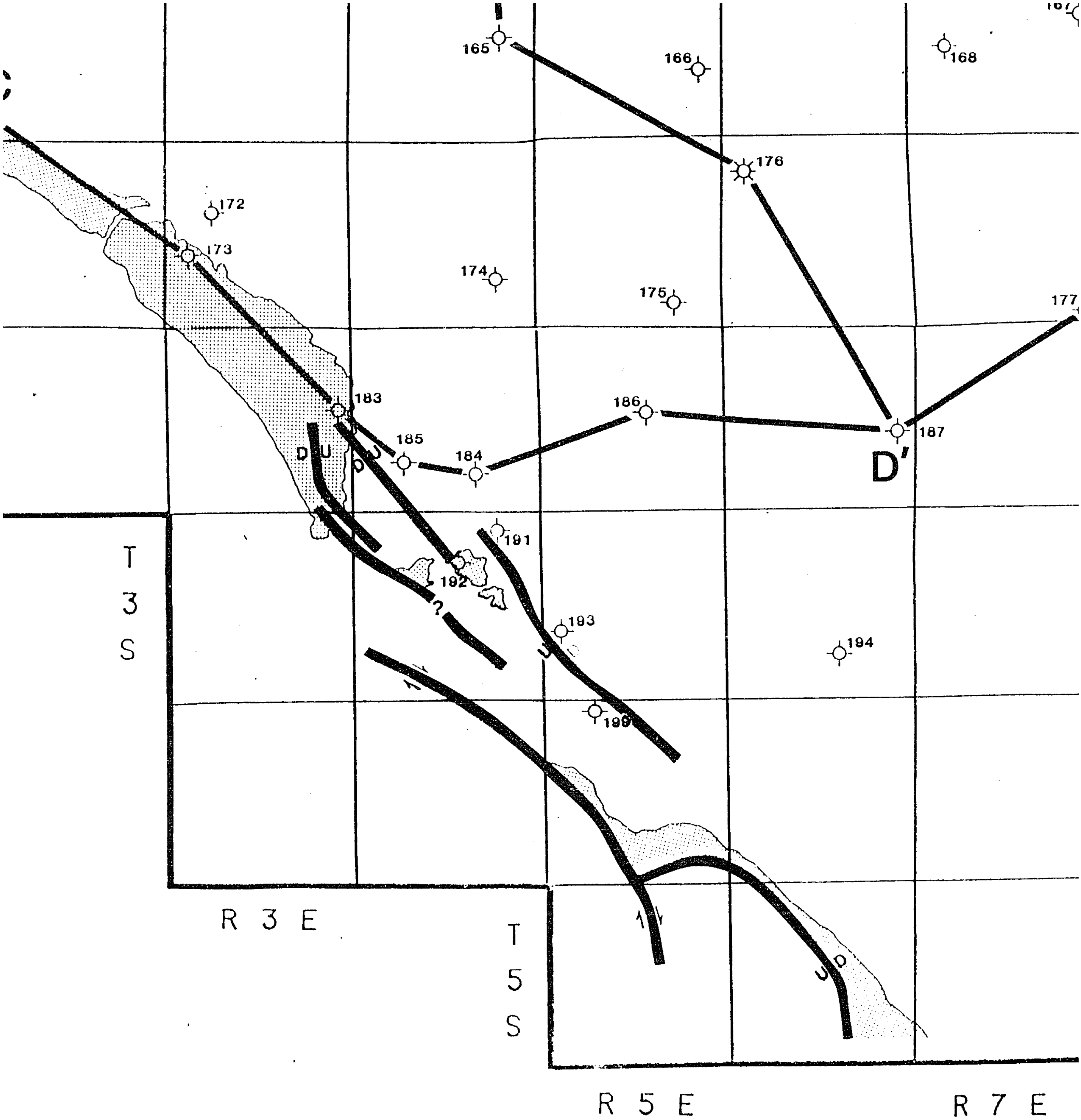


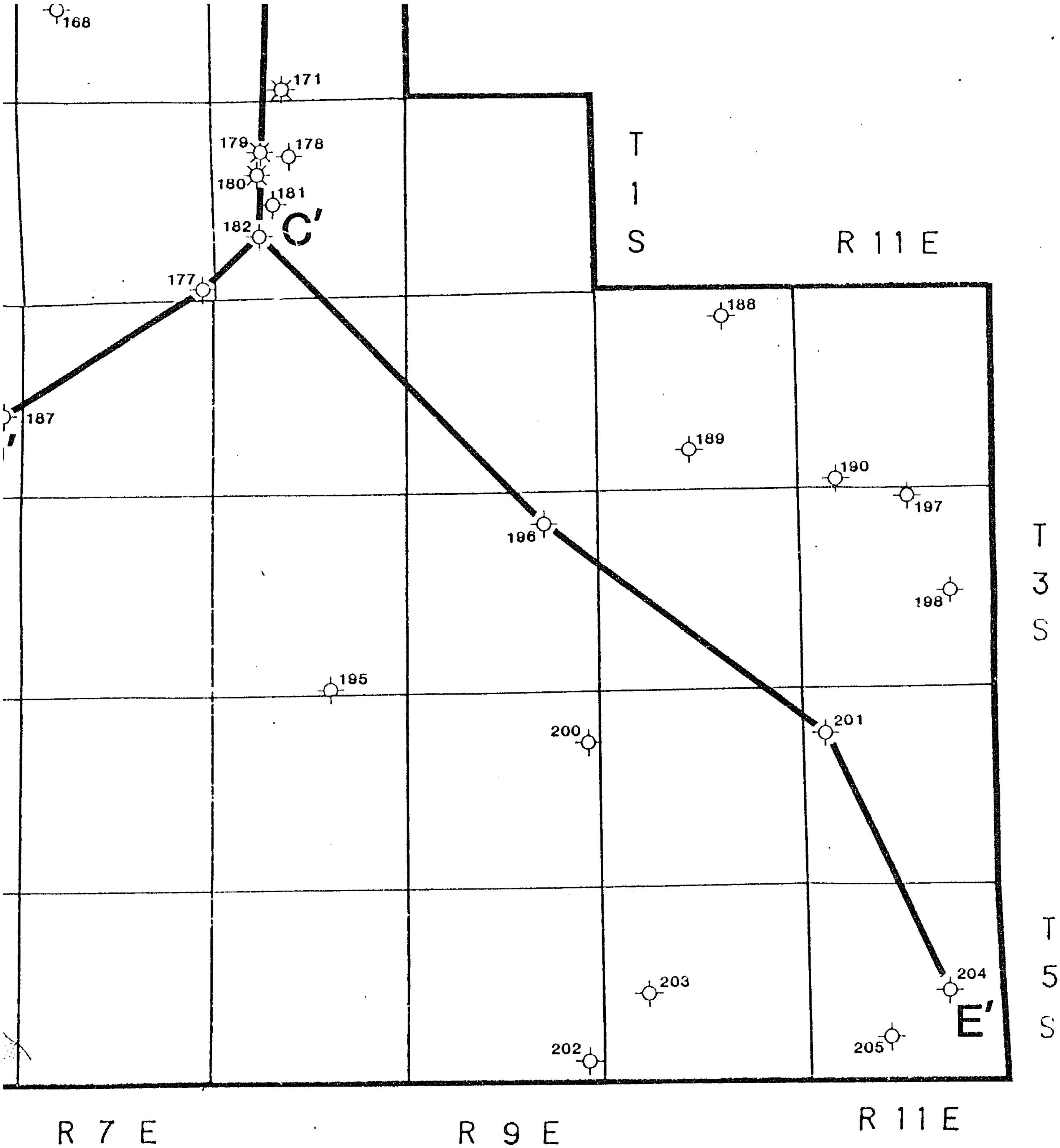
85
89
90
98
101
100
99
T108
102
103
104
105
91
92
93
116
115
117
113
118
119
112
121
110
123
124
125
122
114
120
129
128
130
131
141
140
139
145
147
150
143
146
148
142
135
137
136
138
151
152
144
155
154
E
158
159
167
168
165
166
176
172
173
174


110
123
124
125
T 6 N
132
145
146
147
148
150
151
152
153
T 4 N
156
157
155
E
158
159
161
160
162
163
164
T 2 N
170
169
167
168
171
179
178
180
181
182
C'
T 1 S
R 11 E

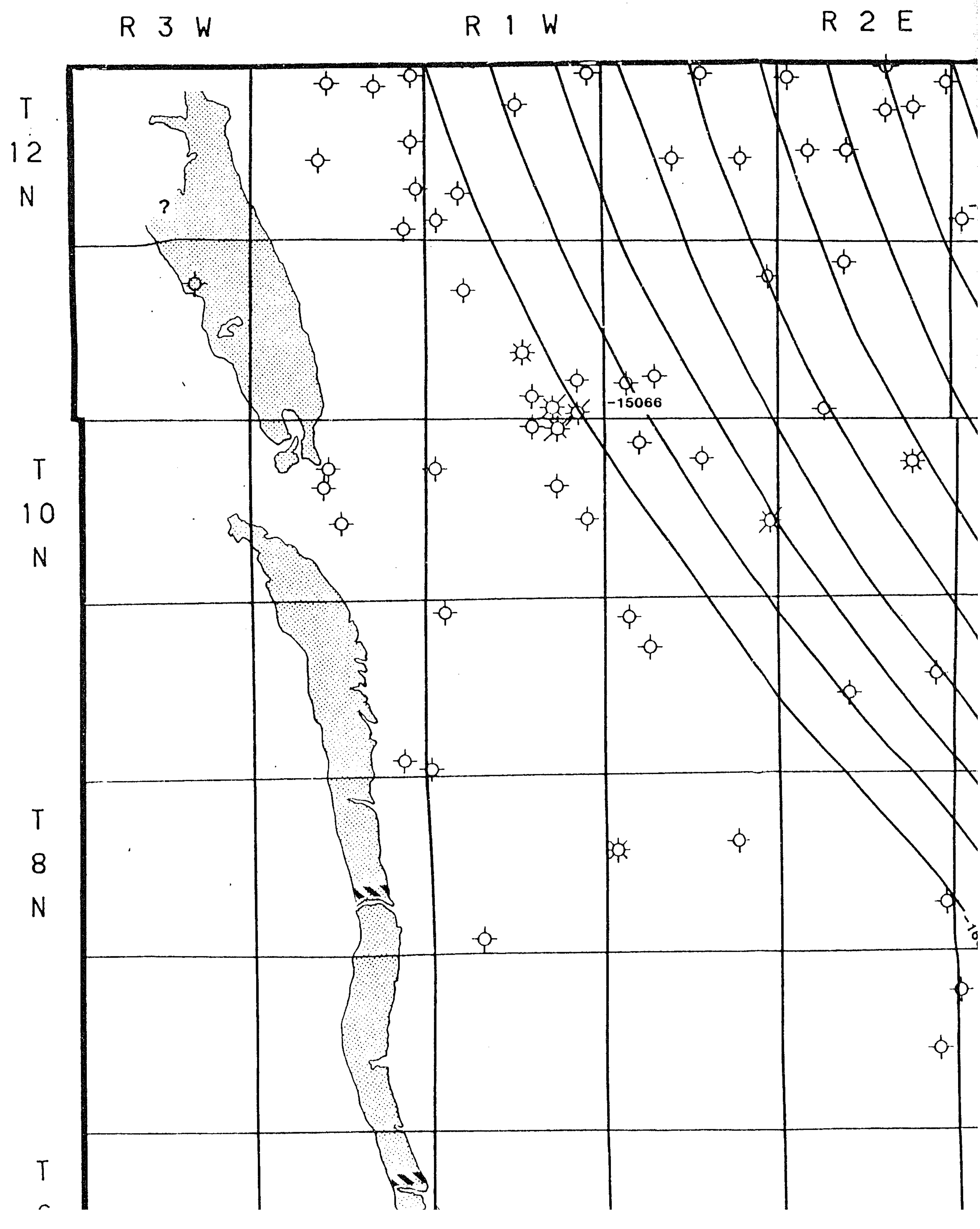


C
Marsh Creek
Measured Section
R 2 W
T
1
S
R 1 E
T
3
S
Plate I – Base Map with Cross Sections
16
Well Identification Number
Dry & Abandoned
Abandoned Producer
Producer
N
0
3
6 mi
F-zone Outcrop
Fault
U-upthrown block, D-downthrown block
arrows indicate sense of movement
Measured Section

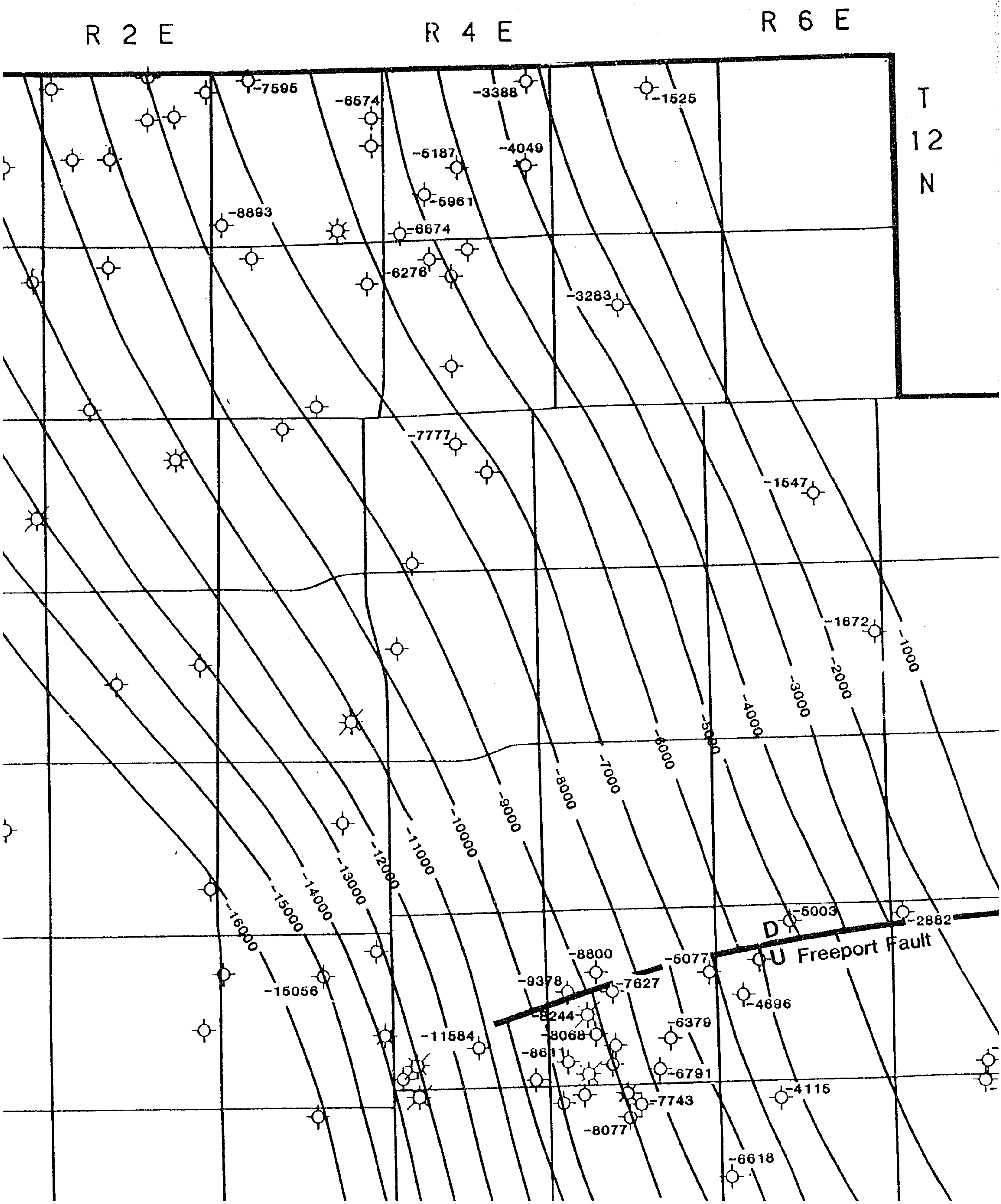

165
166
168
176
172
173
174
175
177
183
186
187
185
184
D'
D U
D U
191
192
?
193
194
199
U D
U D
T
3
S
R 3 E
T
5
S
R 5 E
R 7 E


168
171
179
178
180
181
182
C'
177
187
T 1 S
R 11 E
188
189
190
197
196
T 3 S
198
195
200
201
203
204
202
205
E'
T 5 S
R 7 E
R 9 E
R 11 E

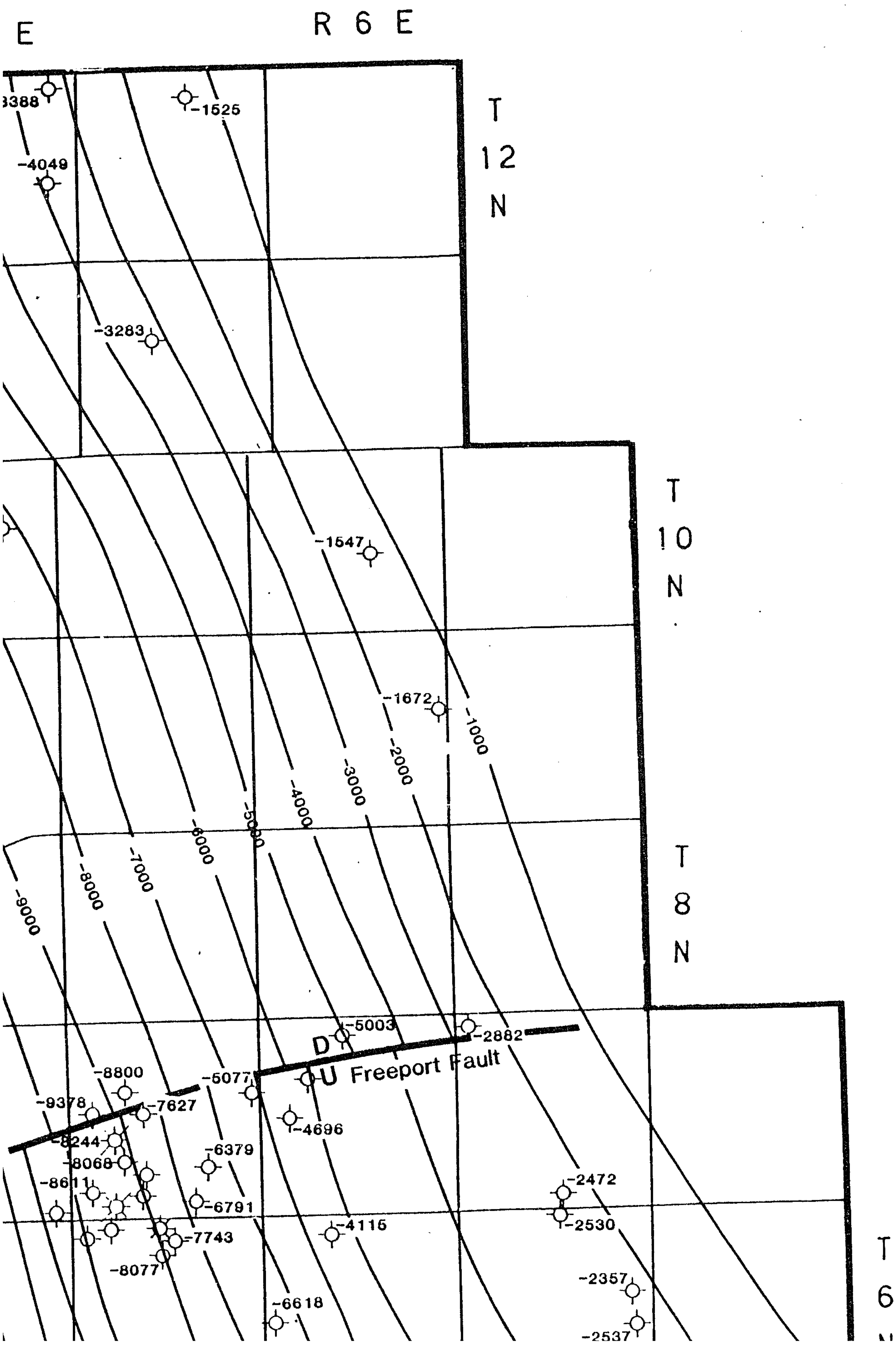
Structure–Contour Map – Top

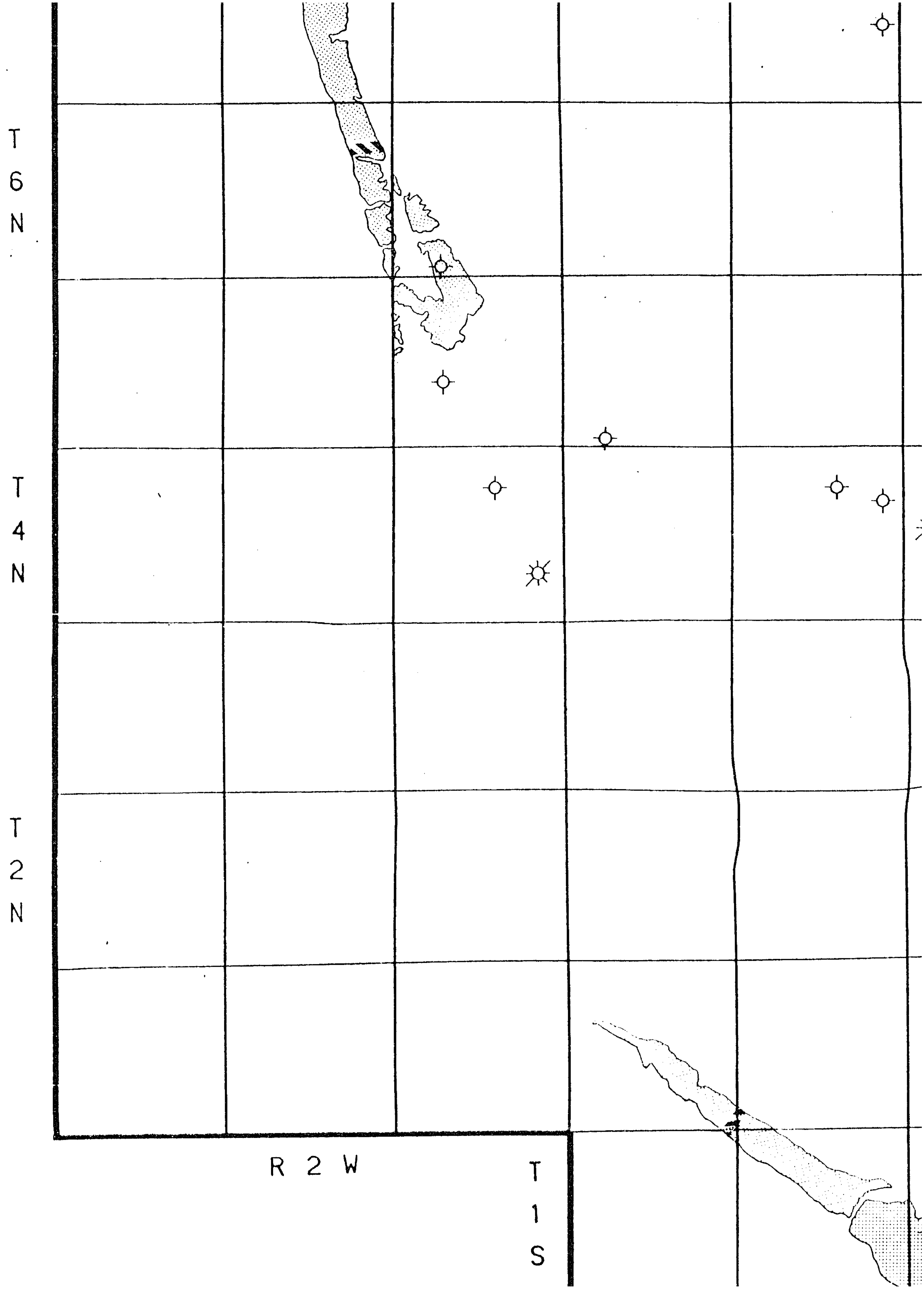


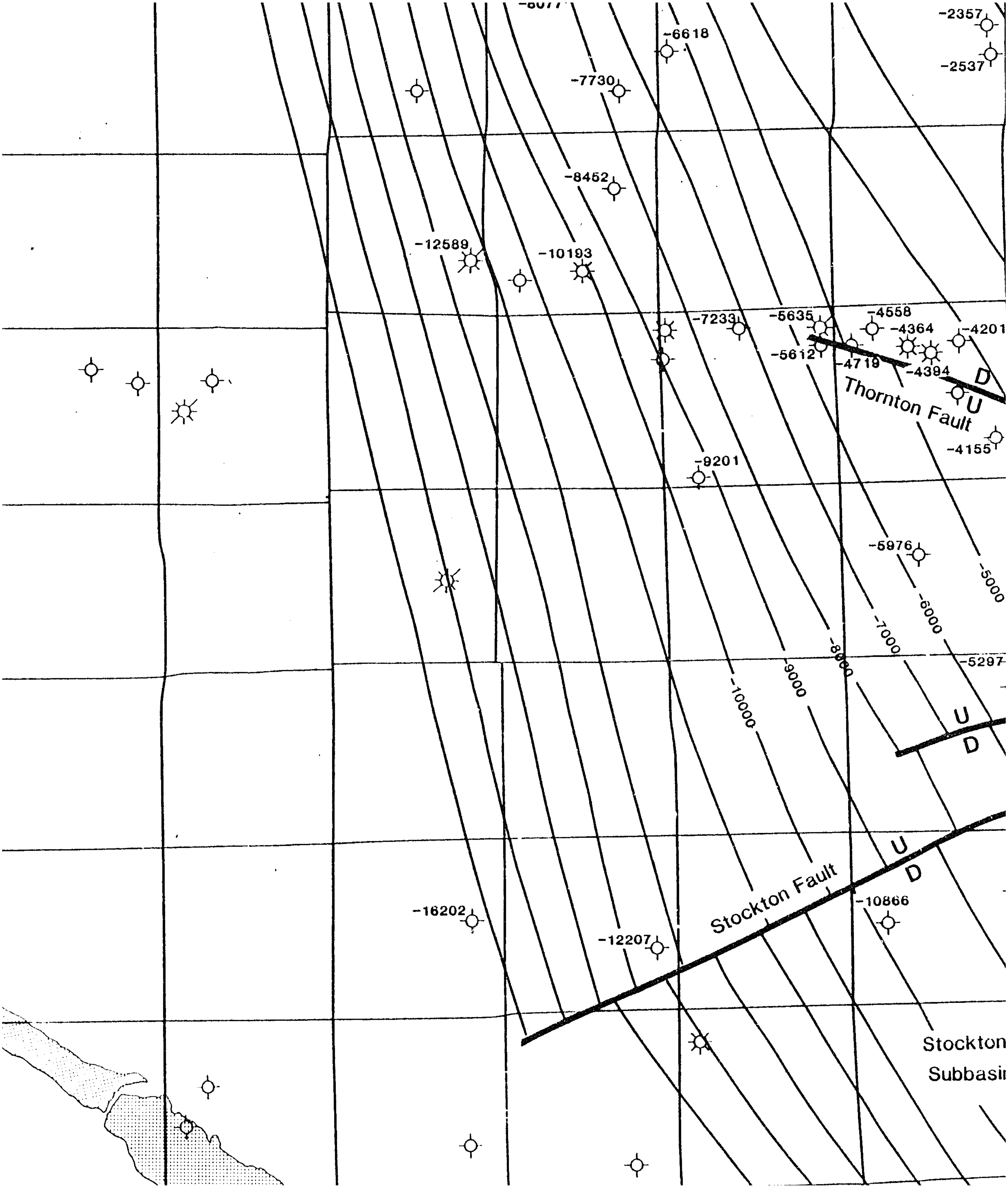
ır Map – Top Basement Rocks

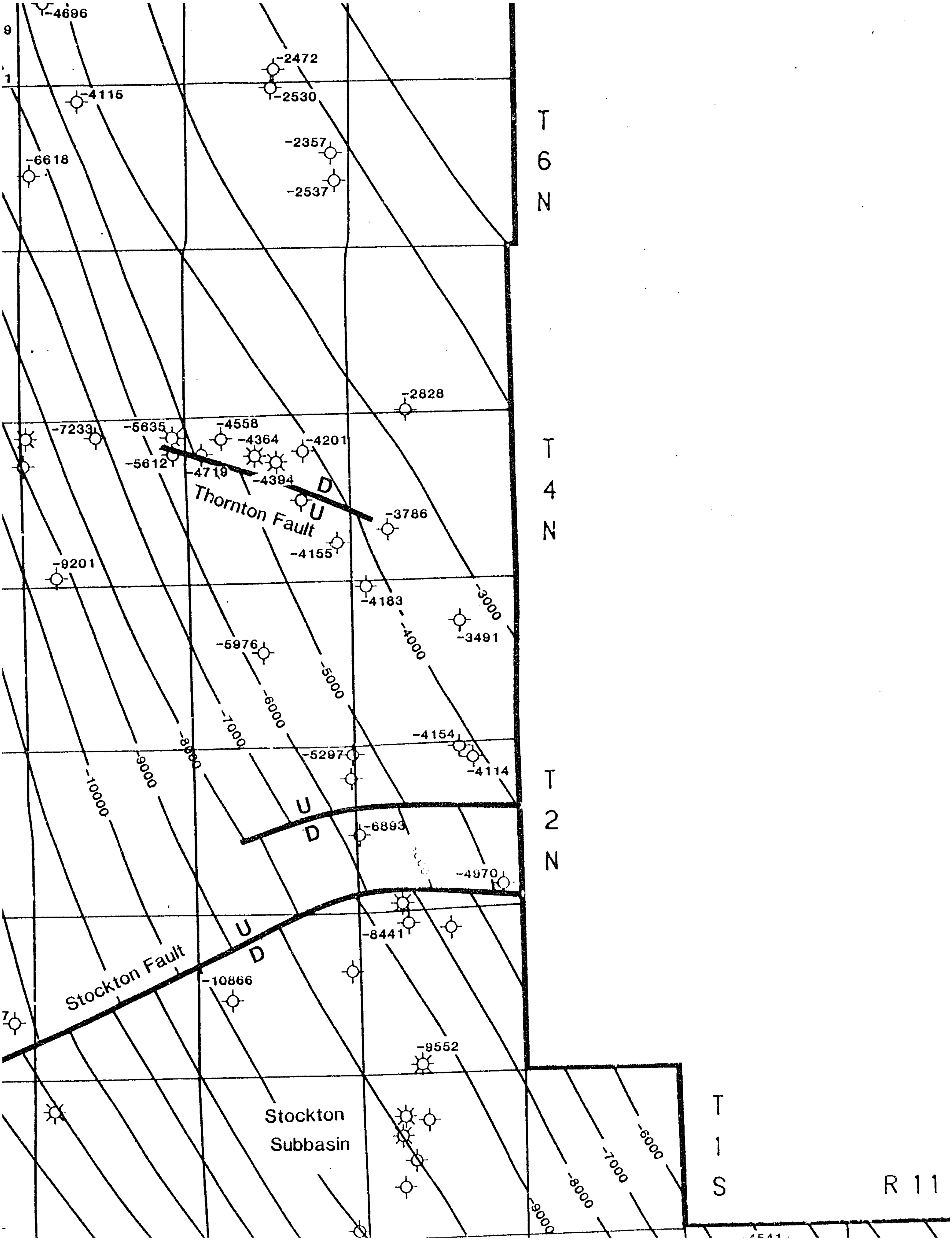


ks

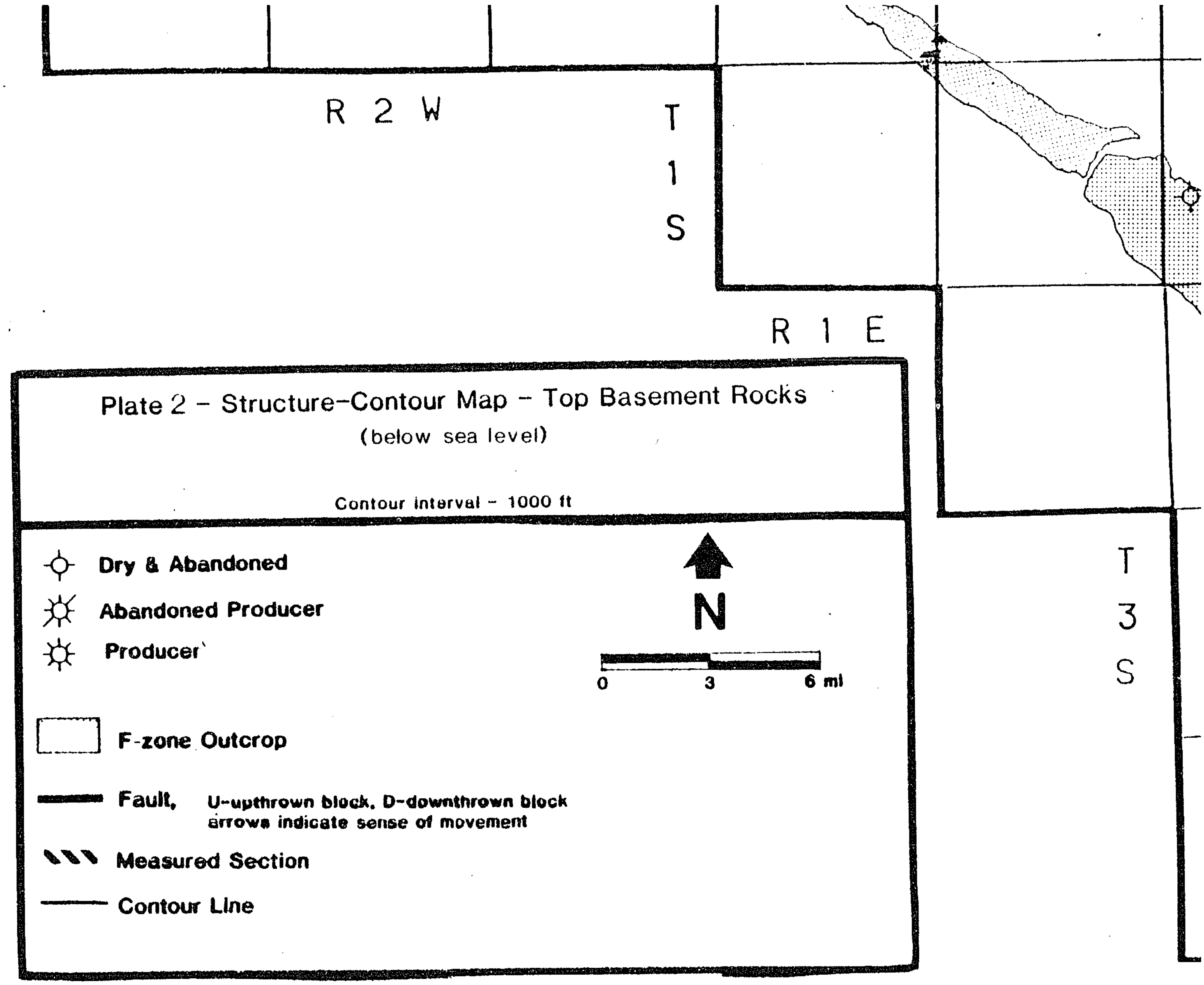

E
R 6 E
T 12 N
T 10 N
T 8 N
T 6 N
-1525
-4049
-3283
-1547
-1672
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-5003
-2882
D
U
Freeport Fault
-8800
-5077
-9378
-7627
-4696
-8244
-6379
-8068
-2472
-8611
-6791
-2530
-4115
-7743
-8077
-2357
-6618
-2537

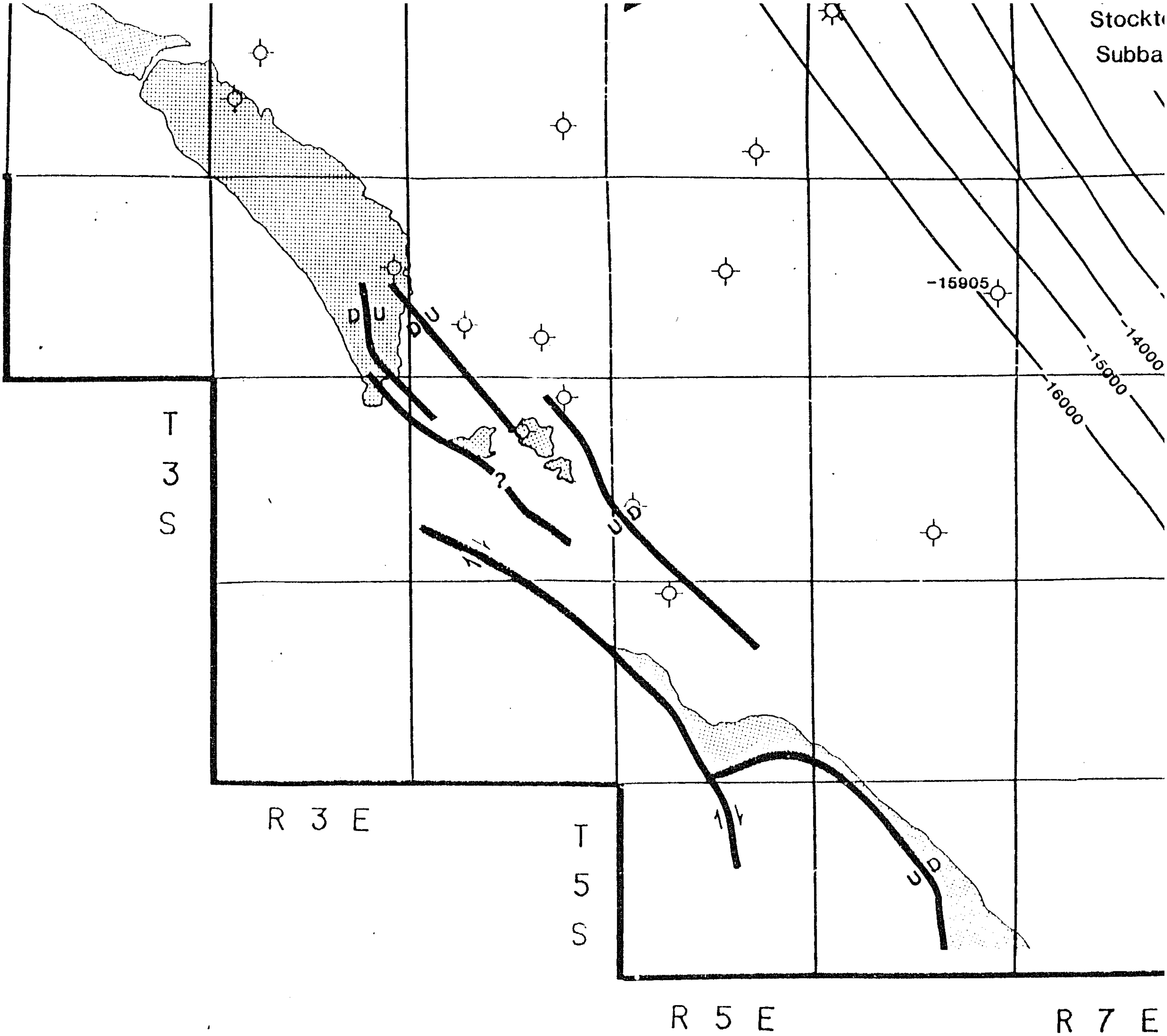

T 6 N
T 4 N
T 2 N
R 2 W
T 1 S


-8077
-6618
-2357
-2537
-7730
-8452
-12589
-10193
-7233
-5635
-4558
-4364
-4201
-5612
-4719
-4394
D
U
Thornton Fault
-4155
-9201
-5976
-5000
-6000
-7000
-8000
-9000
-10000
-5297
U
D
U
D
Stockton Fault
-10866
-16202
-12207
Stockton
Subbasin

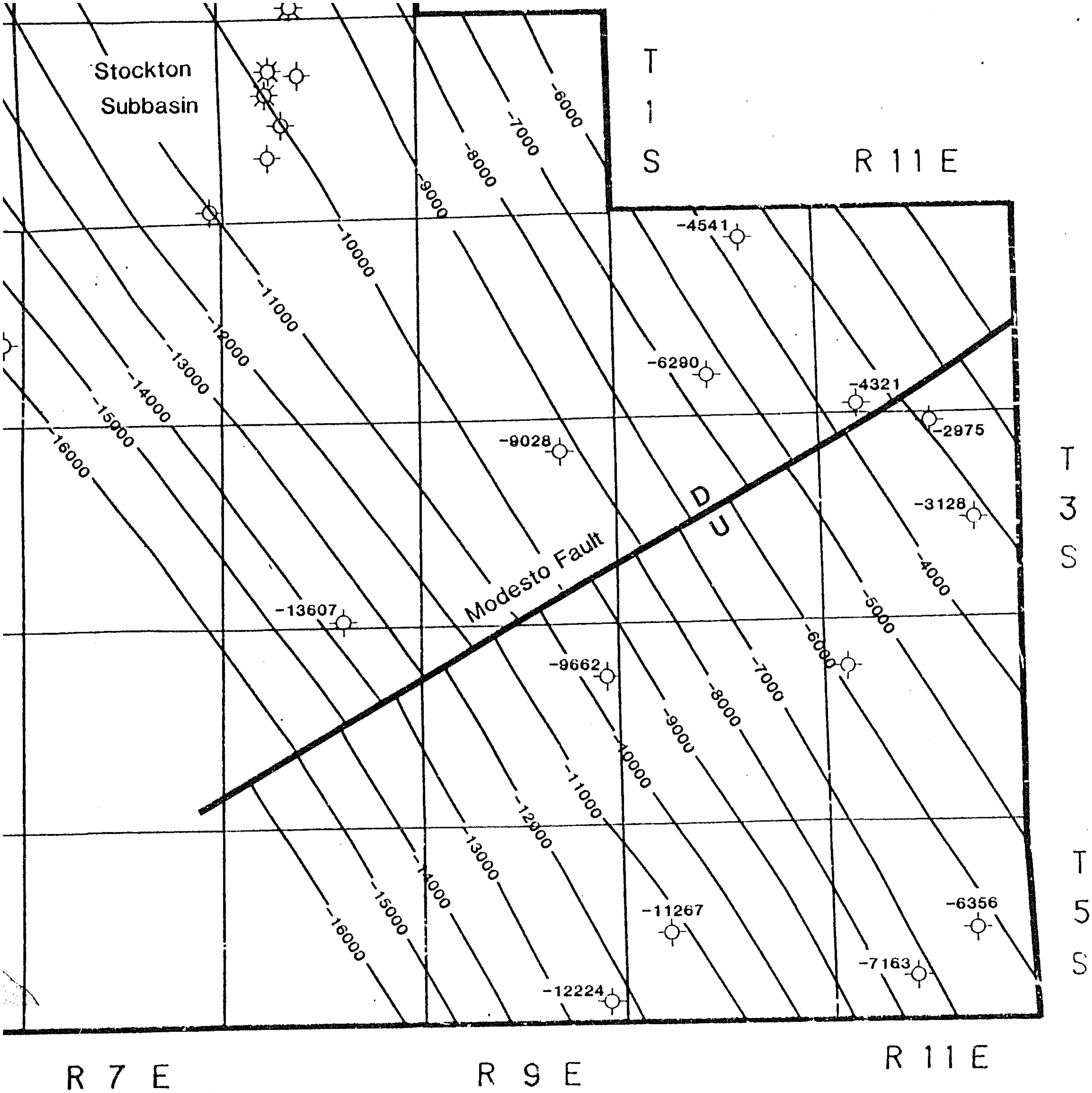


T 6 N
T 4 N
T 2 N
T 1 S
R 11
Thornton Fault
Stockton Fault
Stockton Subbasin
U
D
-4696
-2472
-2530
-4115
-2357
-2537
-6618
-2828
-7233
-5635
-4558
-4364
-4201
-5612
-4719
-4394
-3786
-4155
-9201
-4183
-3491
-5976
-4154
-5297
-4114
-6893
-4970
-8441
-10866
-9552
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000

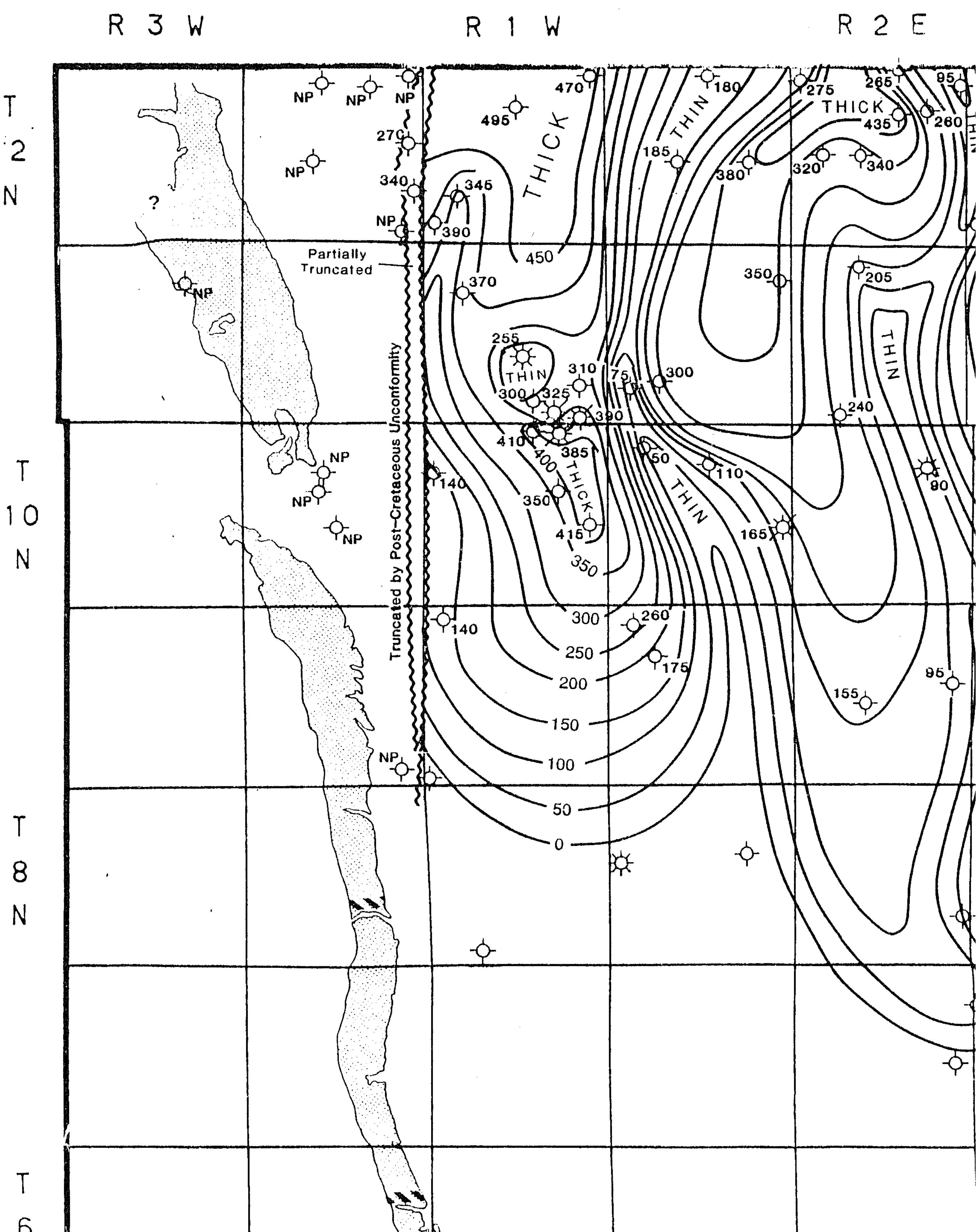

R 2 W
T 1 S
R 1 E
T 3 S
Plate 2 - Structure-Contour Map - Top Basement Rocks
(below sea level)
Contour interval - 1000 ft
Dry & Abandoned
Abandoned Producer
Producer
N
0 3 6 mi
F-zone Outcrop
Fault, U-upthrown block, D-downthrown block
arrows indicate sense of movement
Measured Section
Contour Line



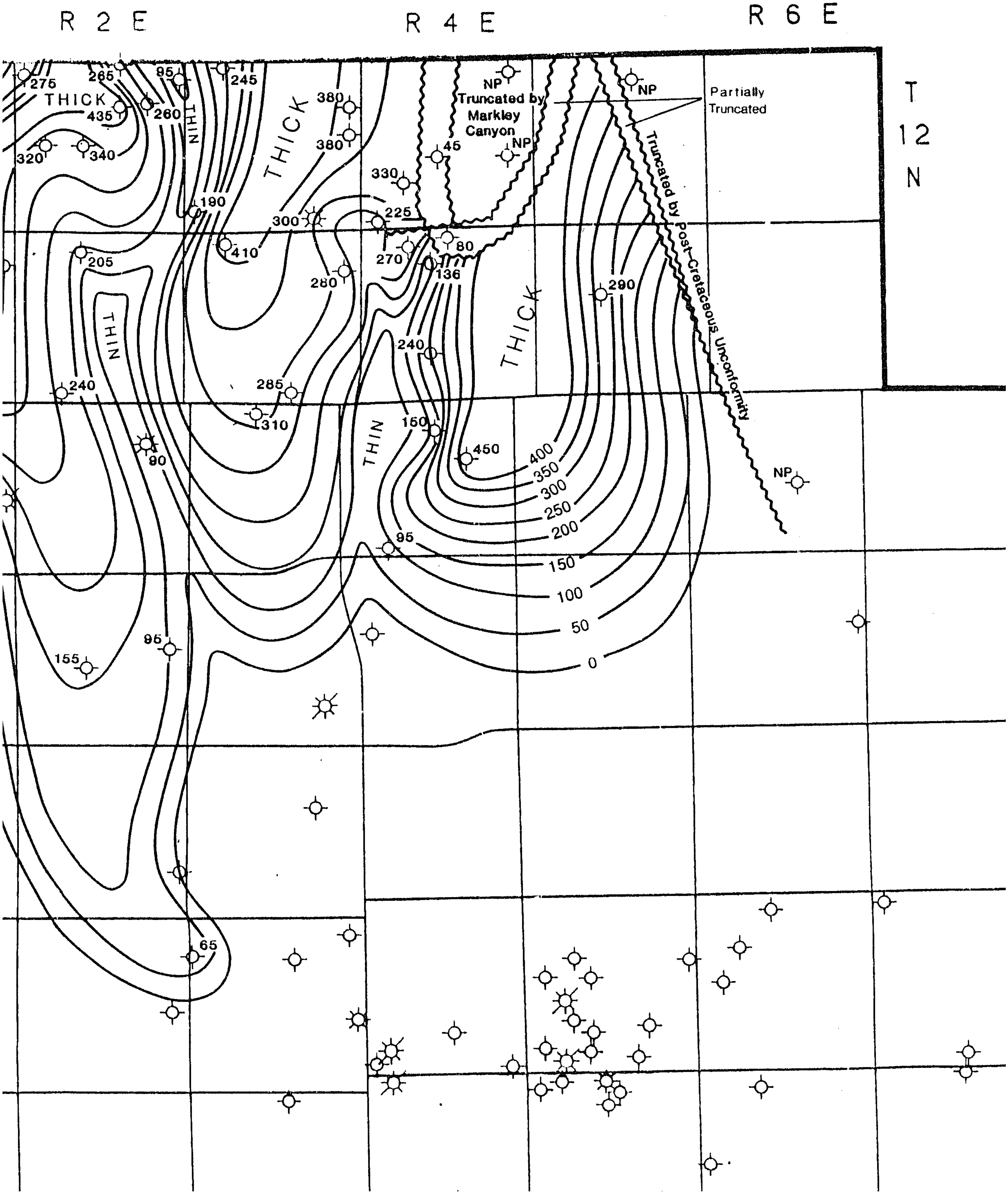
Stockt
Subba
-15905
-14000
-15000
-16000
D U
D U
?
U D
T
3
S
R 3 E
T
5
S
U D
R 5 E
R 7 E

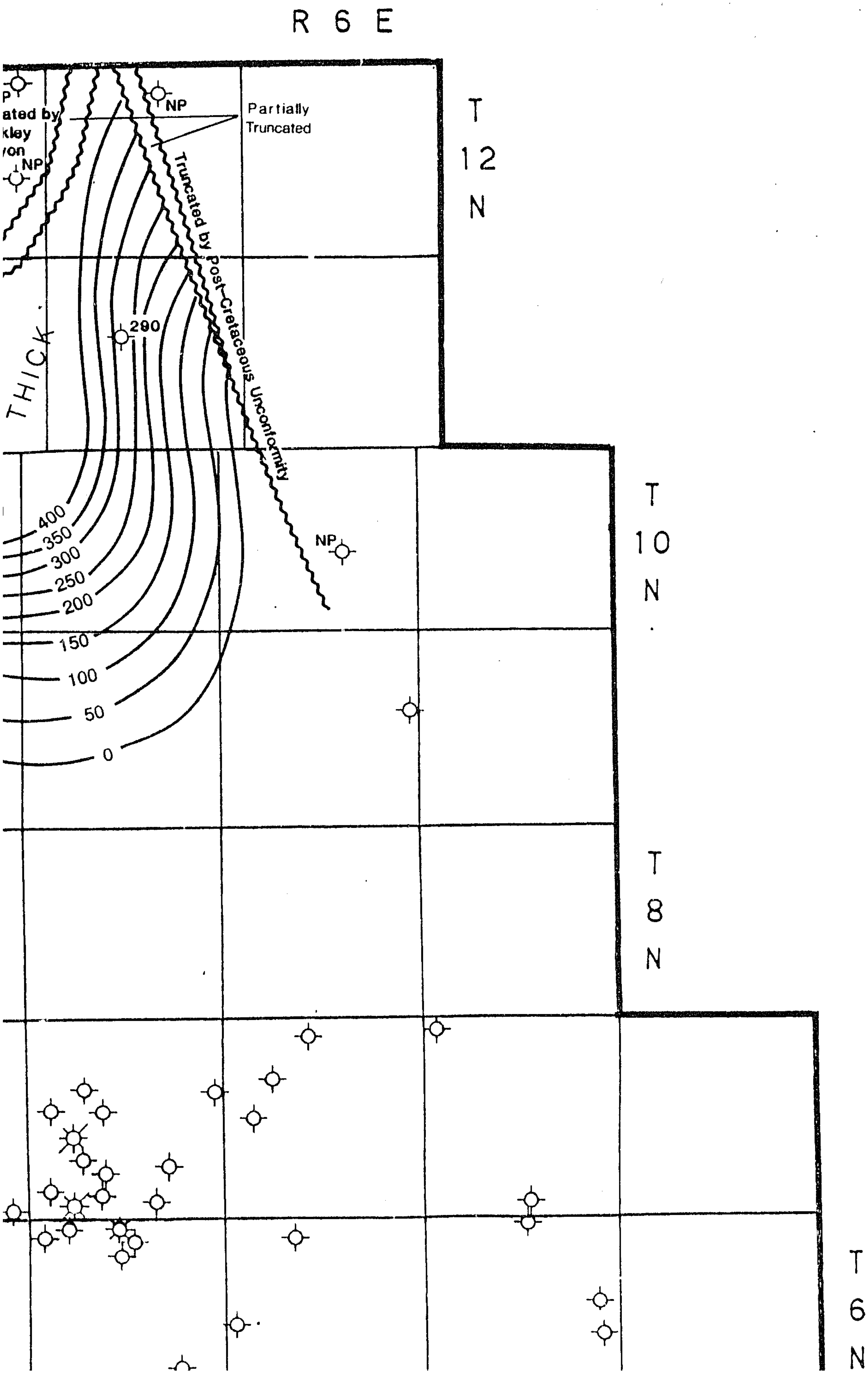

Stockton
Subbasin
T
1
S
R 11 E
-6000
-7000
-8000
-9000
-10000
-11000
-12000
-13000
-14000
-15000
-16000
-4541
-6290
-4321
-2975
-9028
-3128
D
U
Modesto Fault
-4000
-5000
-13607
-9662
-6000
-7000
-8000
-9000
-10000
-11000
-12000
-13000
-14000
-15000
-16000
-11267
-6356
-7163
-12224
T
3
S
T
5
S
R 7 E
R 9 E
R 11 E

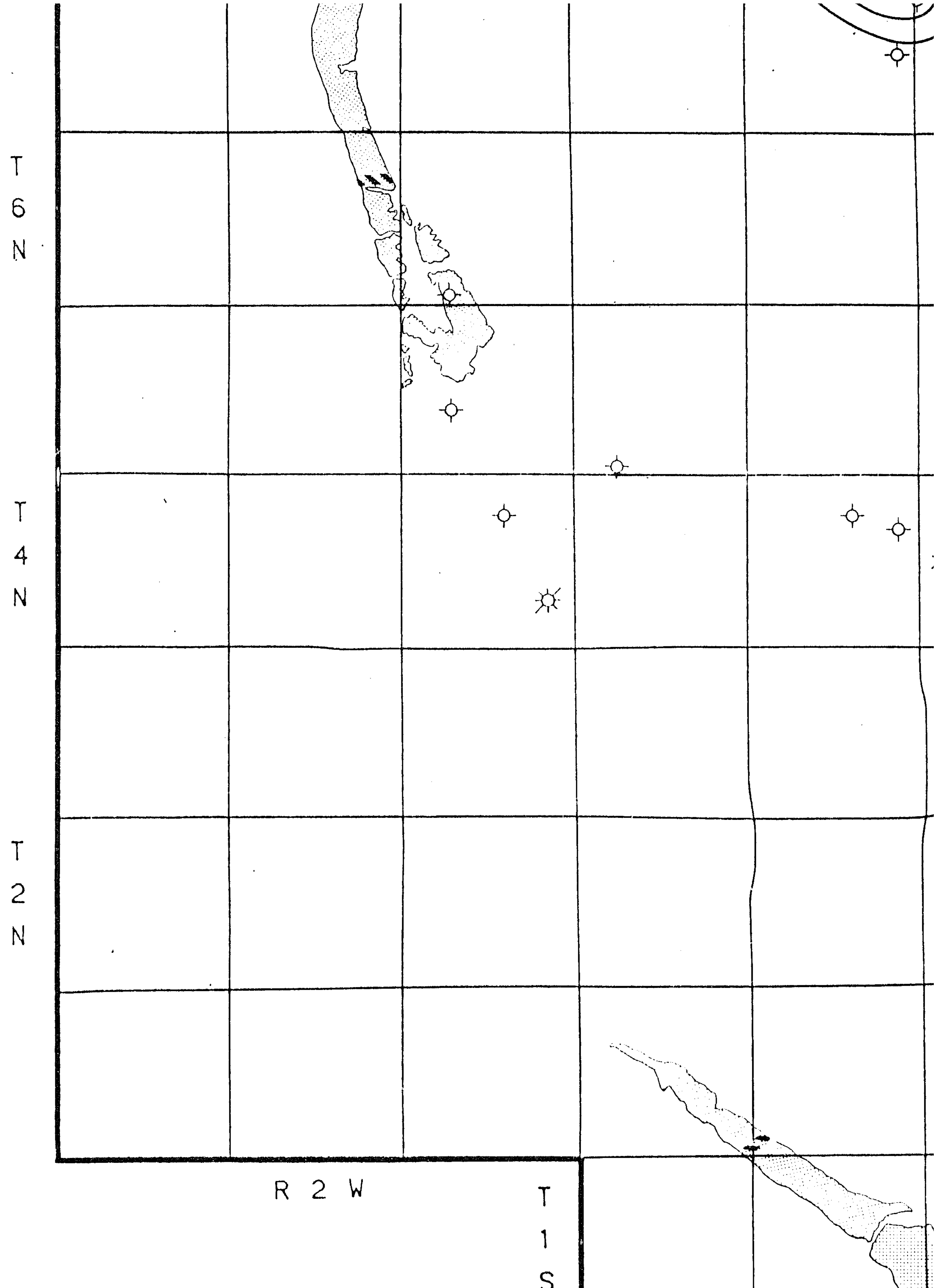
Isopach Map - Kion

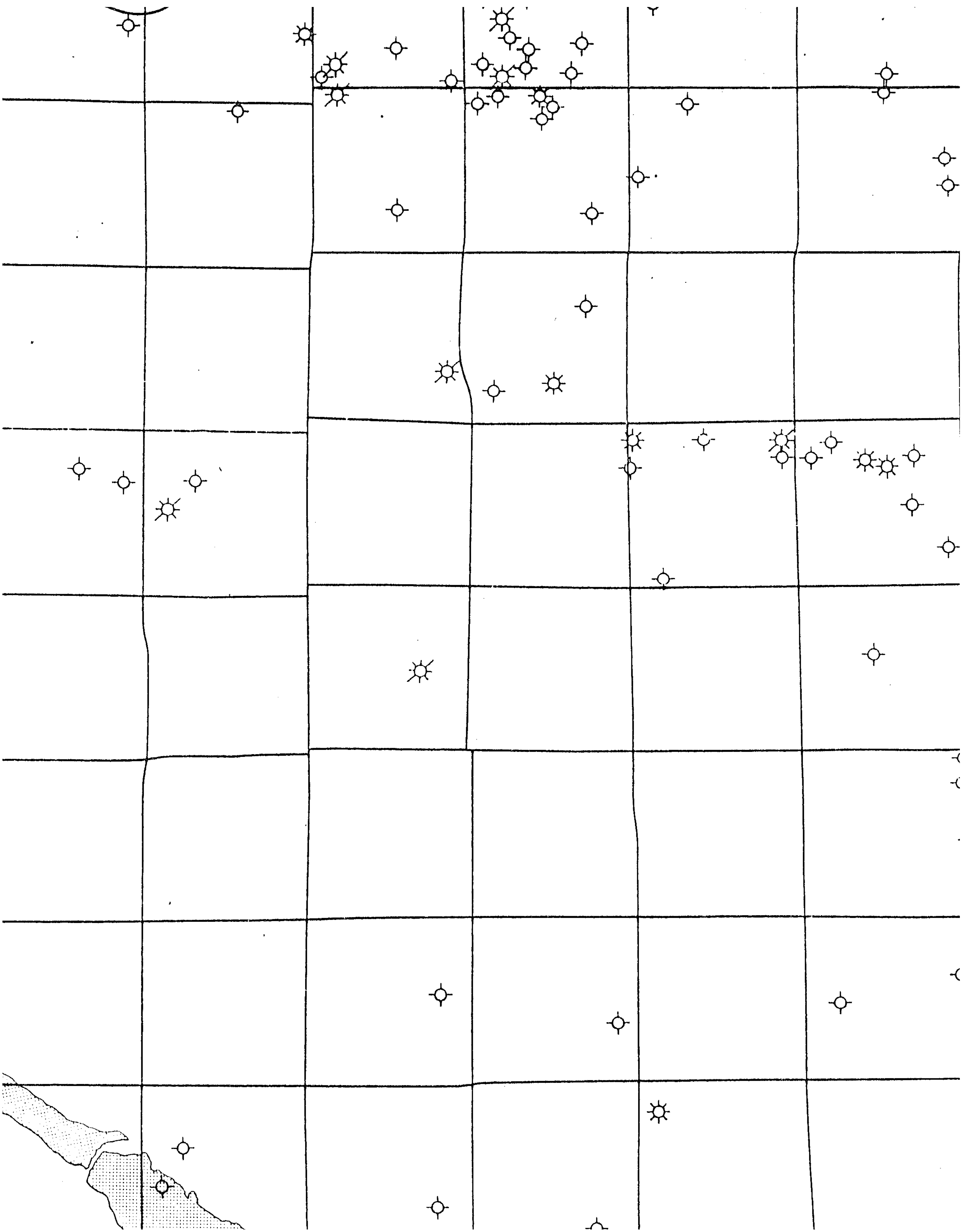


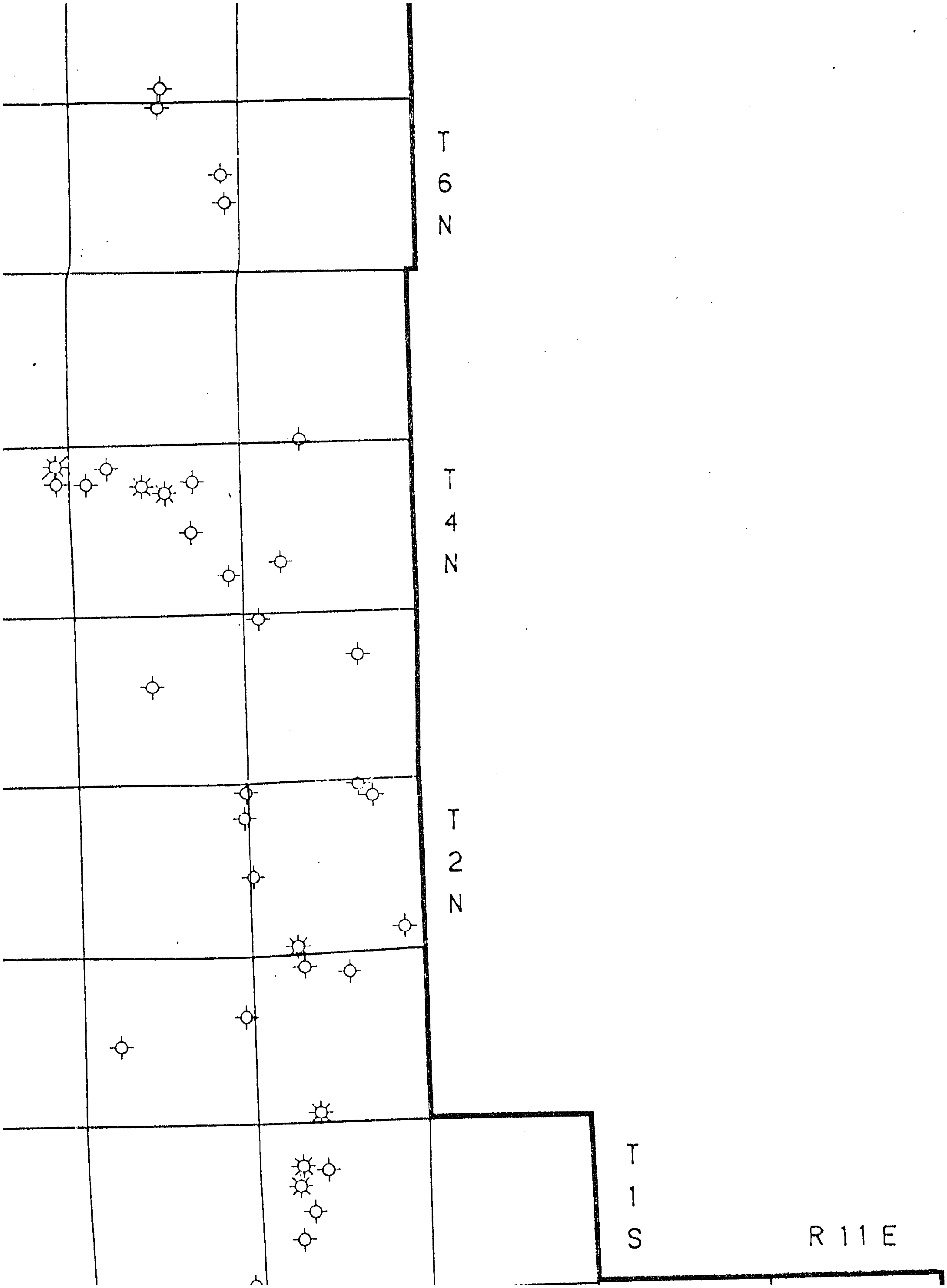
Map – Kione Formation



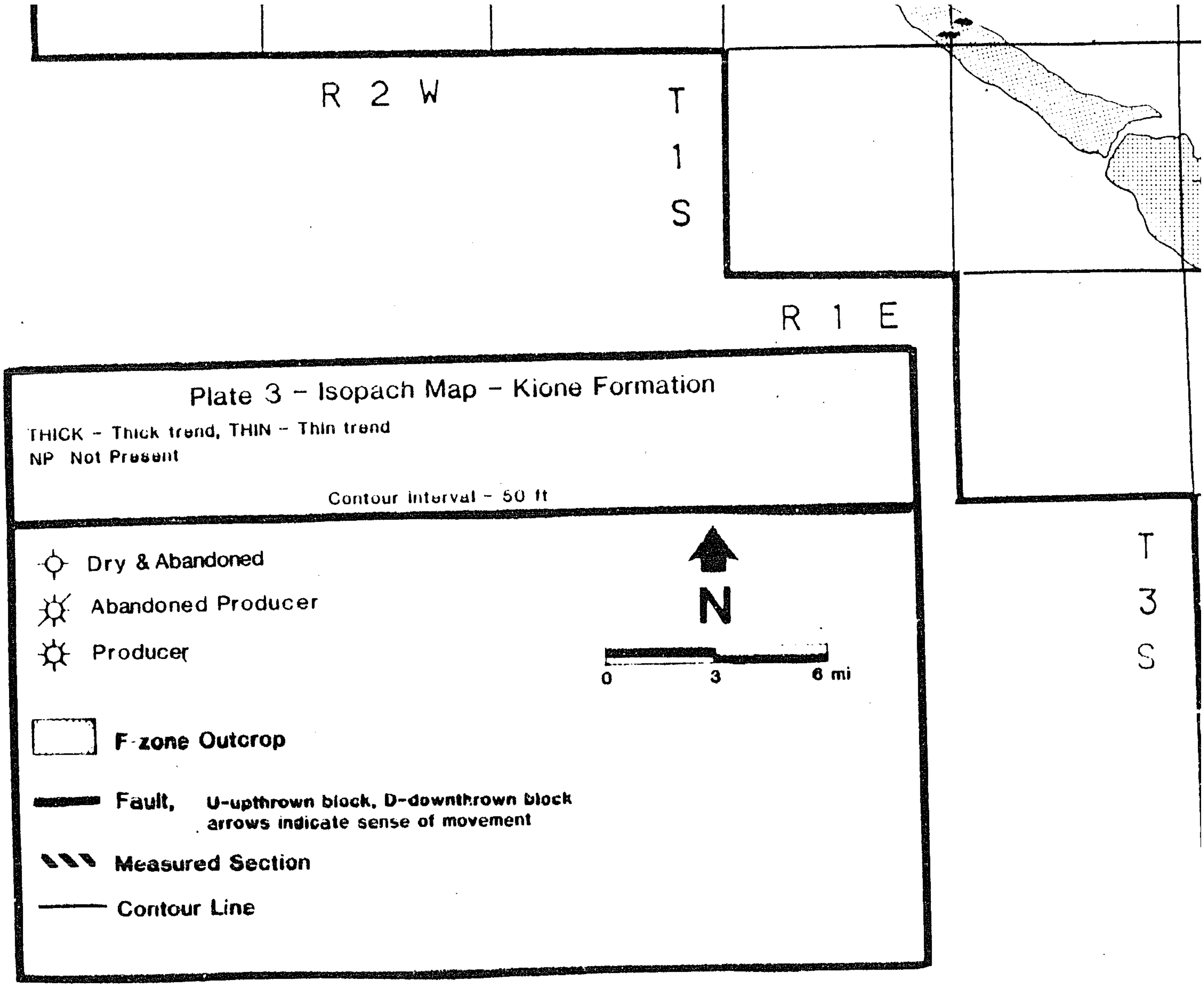

R 6 E
T 12 N
T 10 N
T 8 N
T 6 N
Partially Truncated
Truncated by Post-Cretaceous Unconformity
ated by
kley
yon
NP
290
THICK
400
350
300
250
200
150
100
50
0

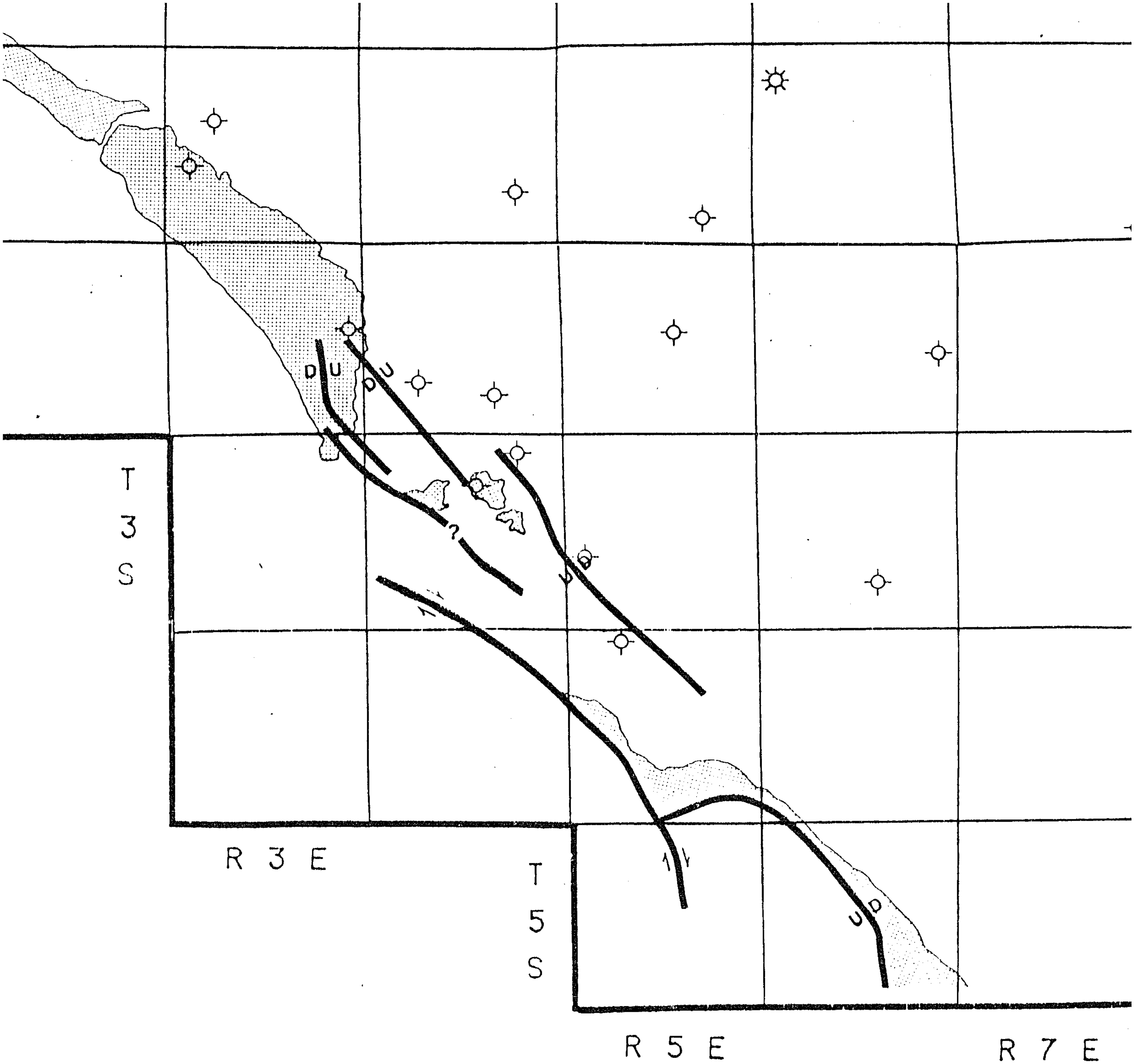

T 6 N
T 4 N
T 2 N
R 2 W
T 1 S



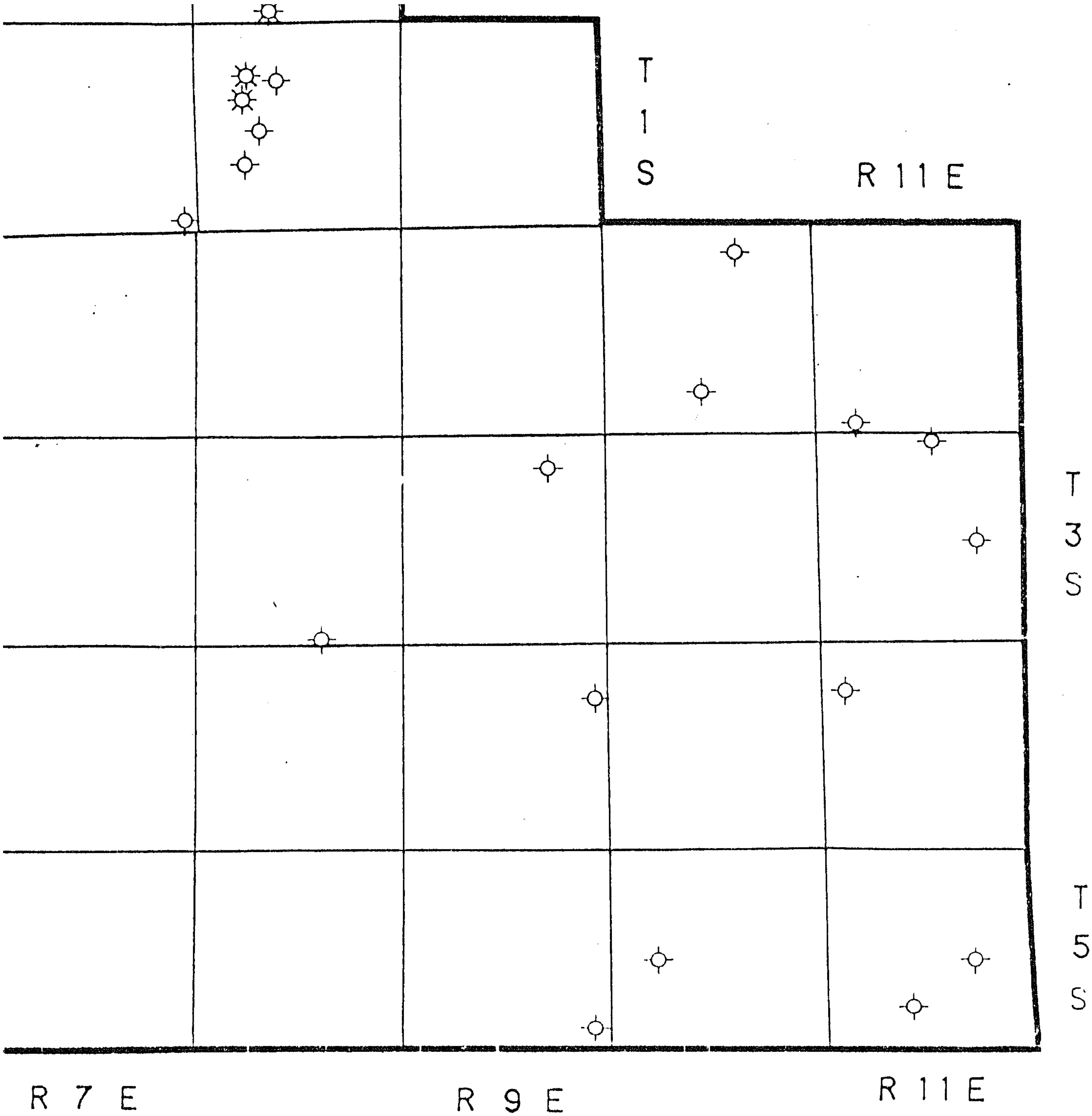


T 6 N
T 4 N
T 2 N
T 1 S
R 11 E


R 2 W
T 1 S
R 1 E
T 3 S
Plate 3 – Isopach Map – Kione Formation
THICK – Thick trend, THIN – Thin trend
NP Not Present
Contour interval – 50 ft
Dry & Abandoned
Abandoned Producer
Producer
N
0
3
6 mi
F-zone Outcrop
Fault, U-upthrown block, D-downthrown block
arrows indicate sense of movement
Measured Section
Contour Line



T
3
S
R 3 E
T
5
S
R 5 E
R 7 E


T 1 S
R 11 E
T 3 S
T 5 S
R 7 E
R 9 E
R 11 E

PLEASE NOTE:

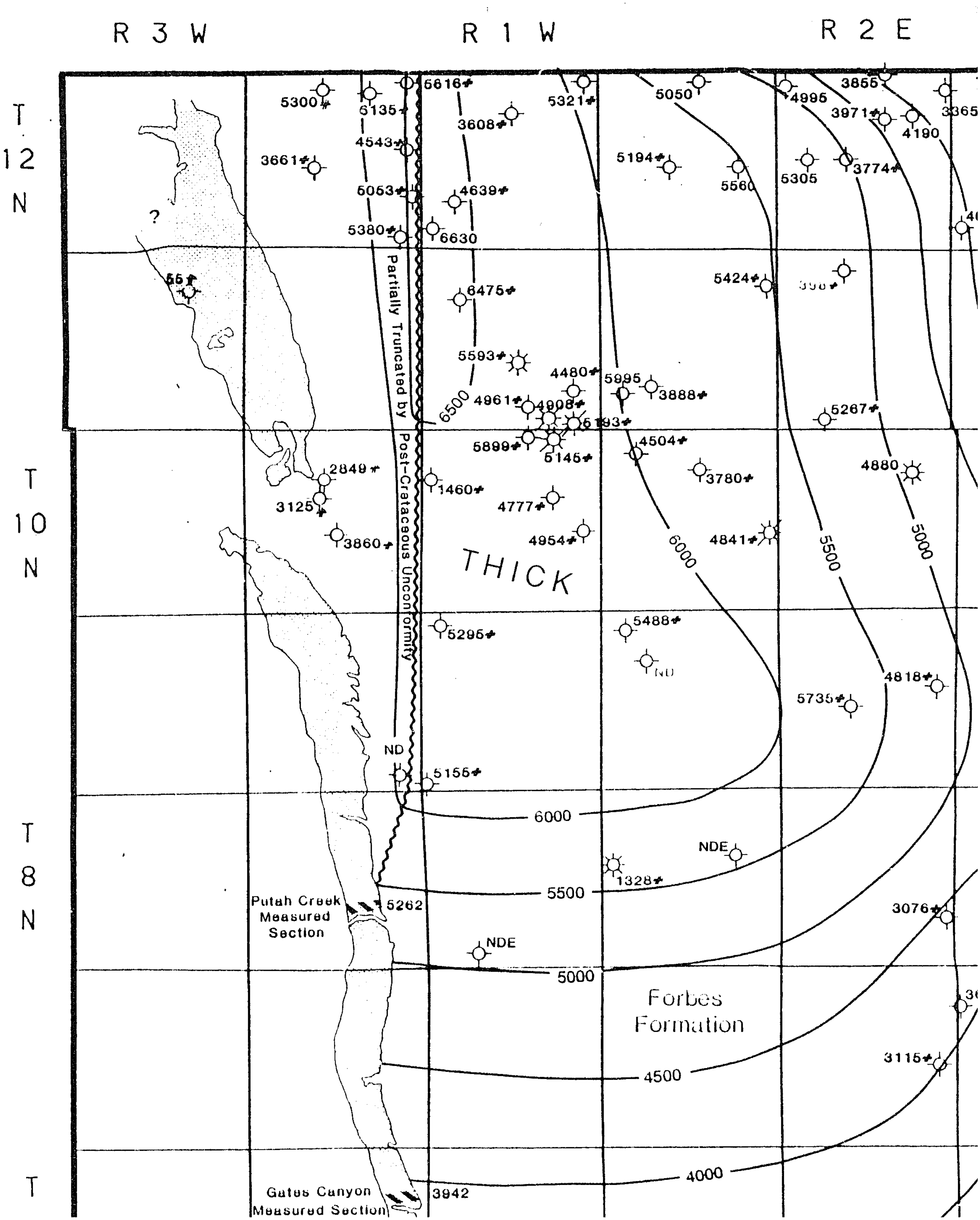
Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

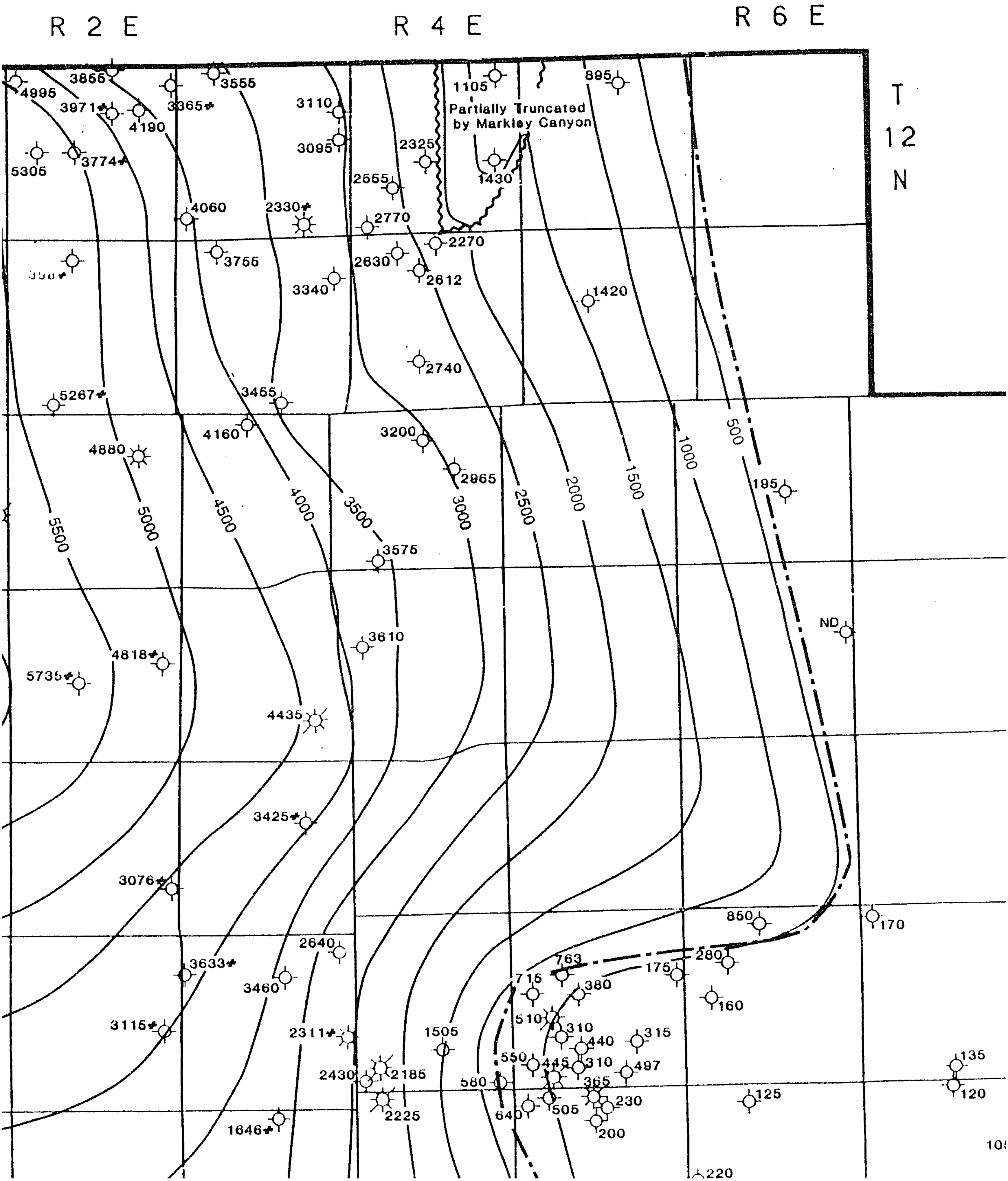
The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Black and white photographic prints (17" x 23") are available for an additional charge.

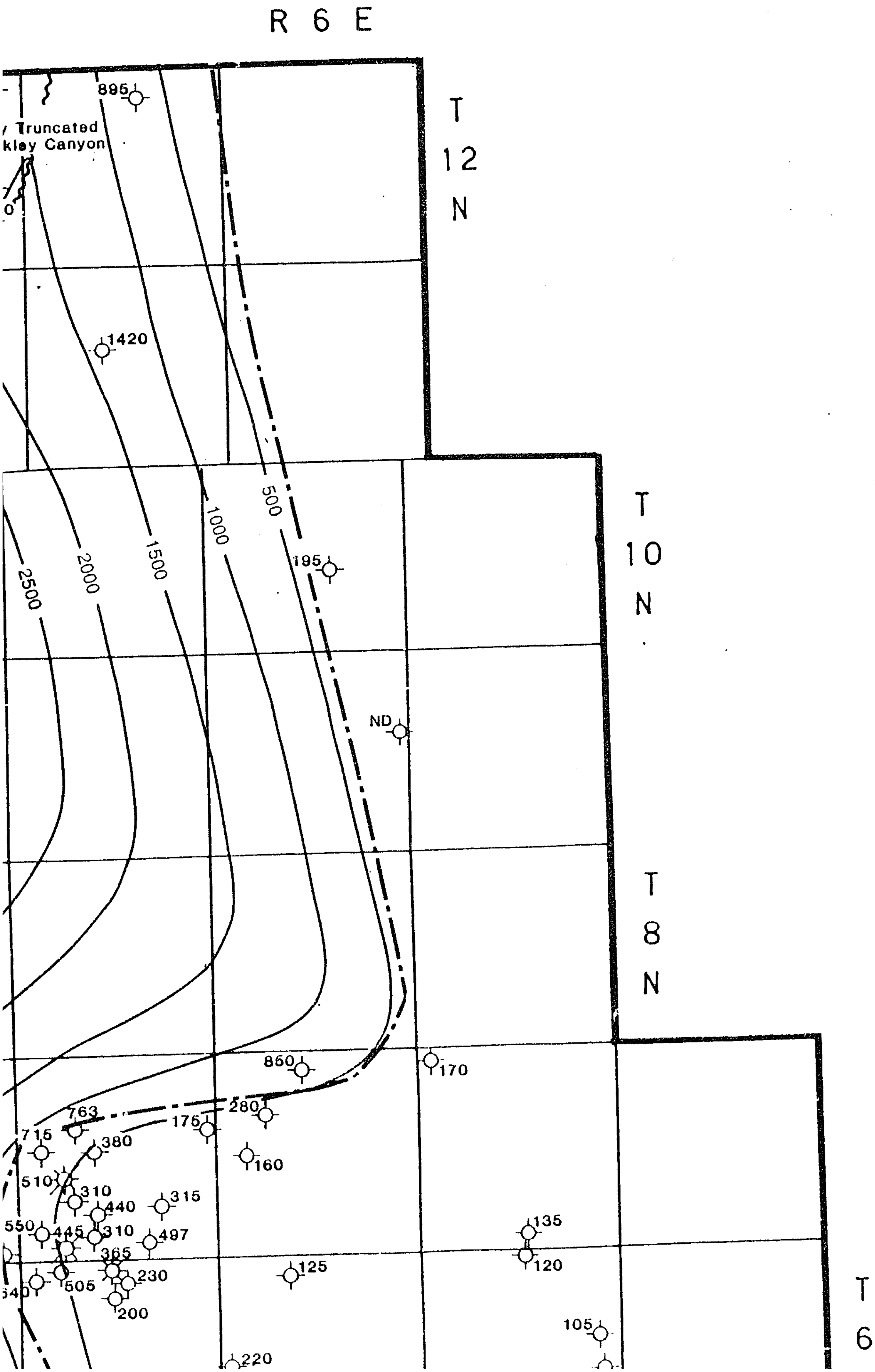
Isopach Map – F



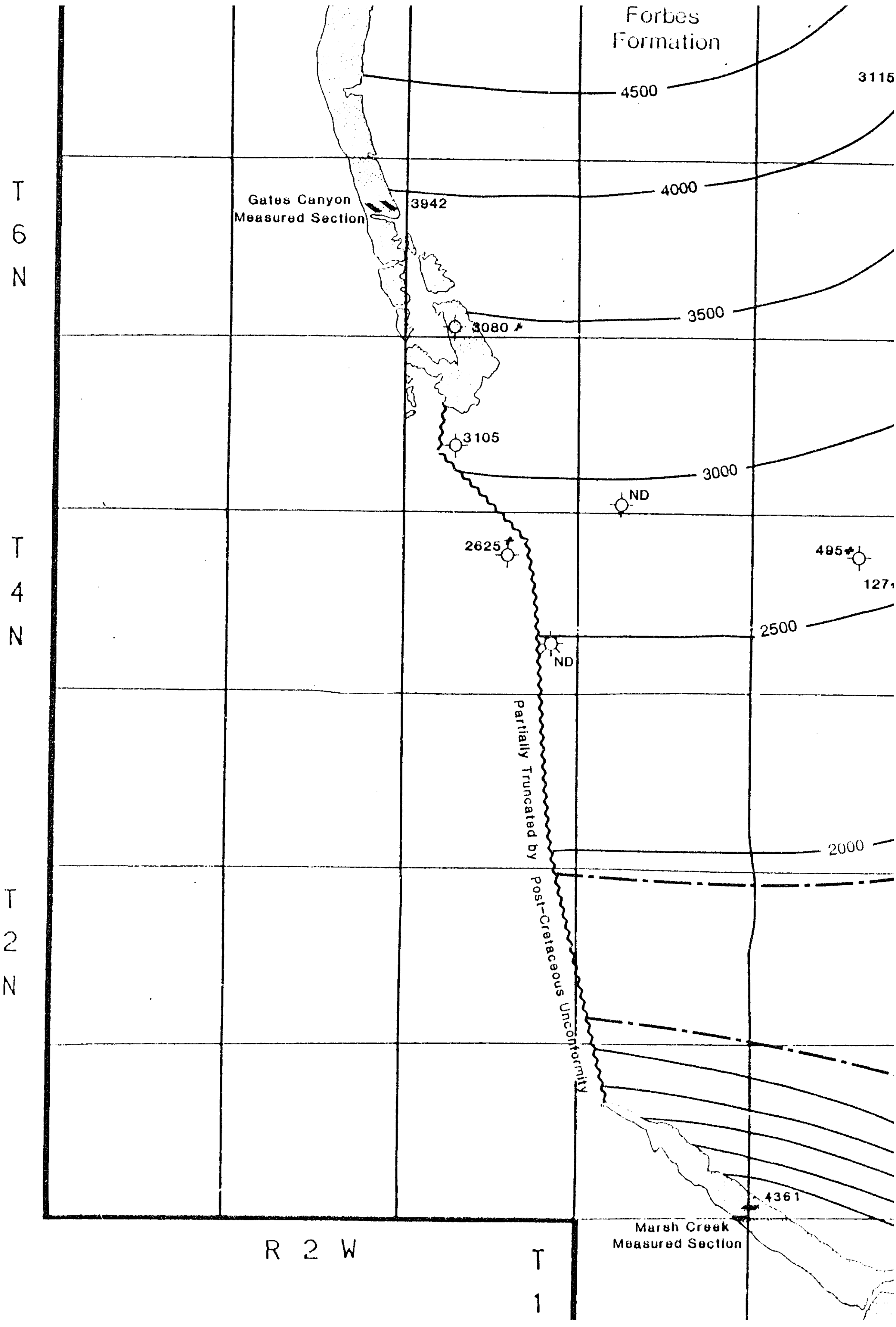
;h Map – F zone

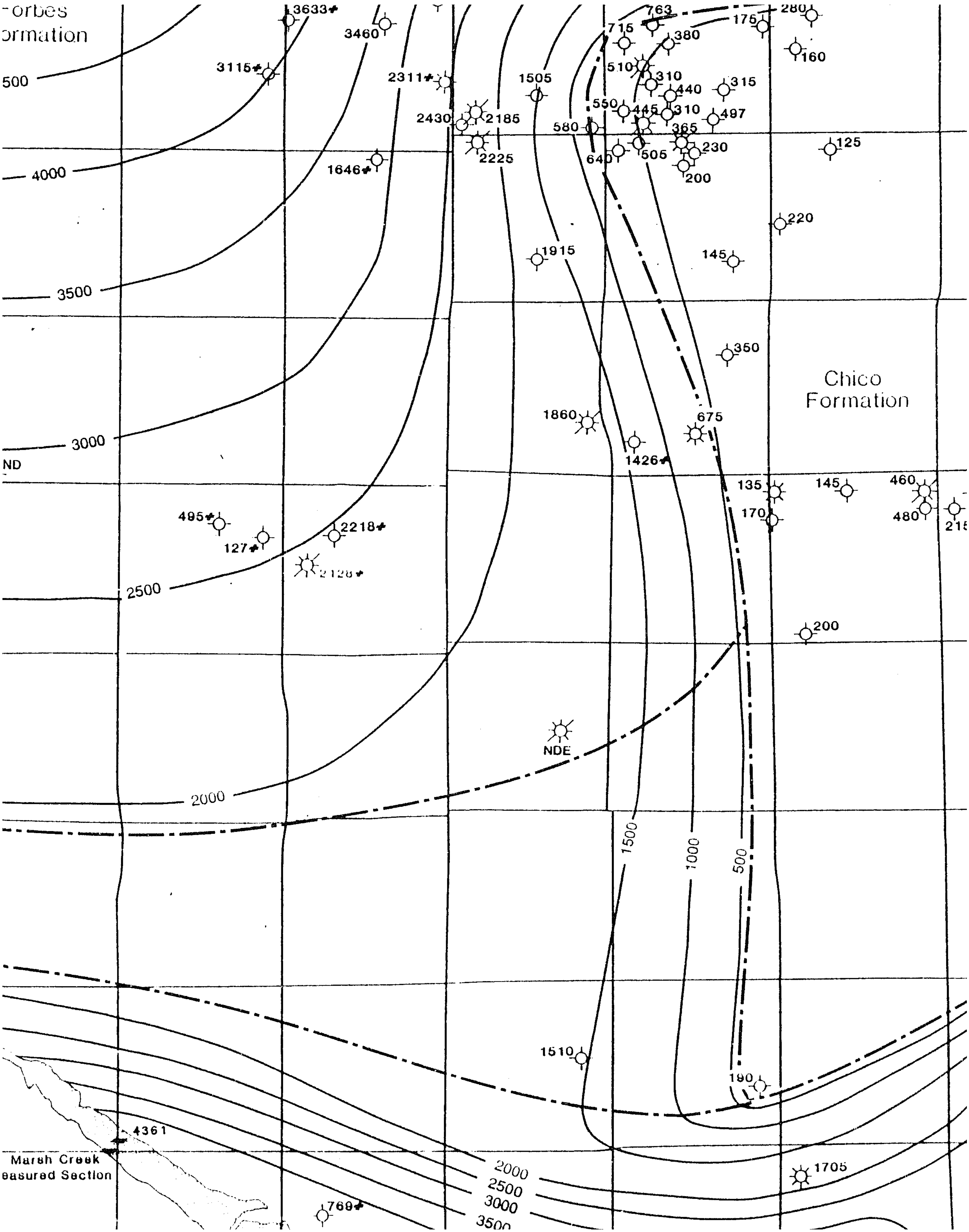


R 2 E
R 4 E
R 6 E
T
12
N
Partially Truncated
by Markley Canyon
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
4995
3855
3555
3971
4190
3365
3110
3095
1105
895
2325
1430
5305
3774
2555
4060
2330
2770
2270
3755
2630
2612
3340
1420
2740
5267
3455
4160
3200
4880
2965
195
3575
ND
3610
4818
5735
4435
3425
3076
850
170
2640
763
280
3633
175
715
380
3460
160
510
3115
310
2311
1505
440
315
550
445
310
497
135
2430
2185
580
365
230
125
120
640
505
2225
1646
200
220

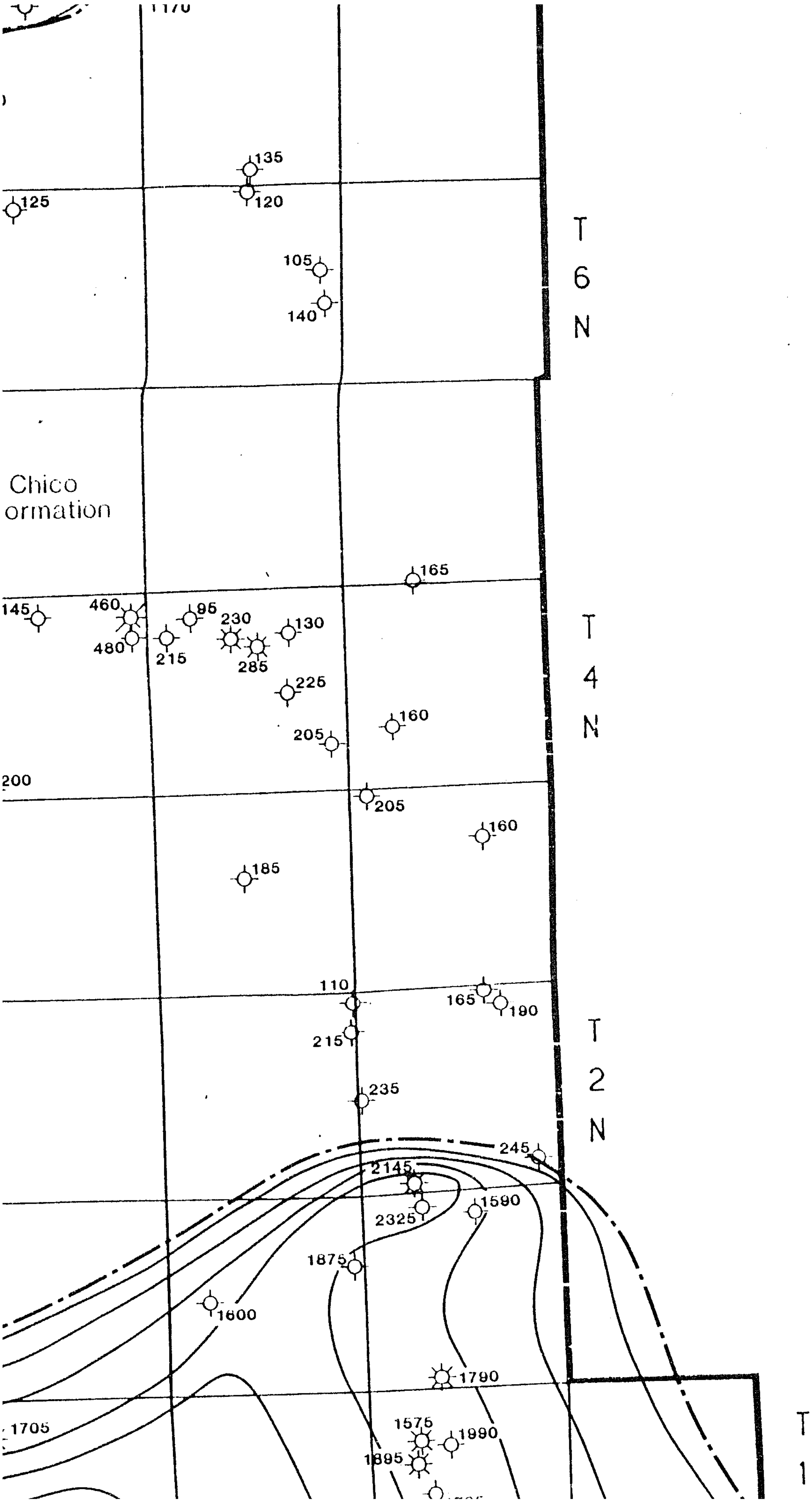


R 6 E
T 12 N
T 10 N
T 8 N
T 6
Truncated
kley Canyon
895
1420
2500
2000
1500
1000
500
195
ND
850
170
763
280
175
715
380
160
510
310
440
315
550
445
310
497
365
230
505
200
135
120
125
105
220

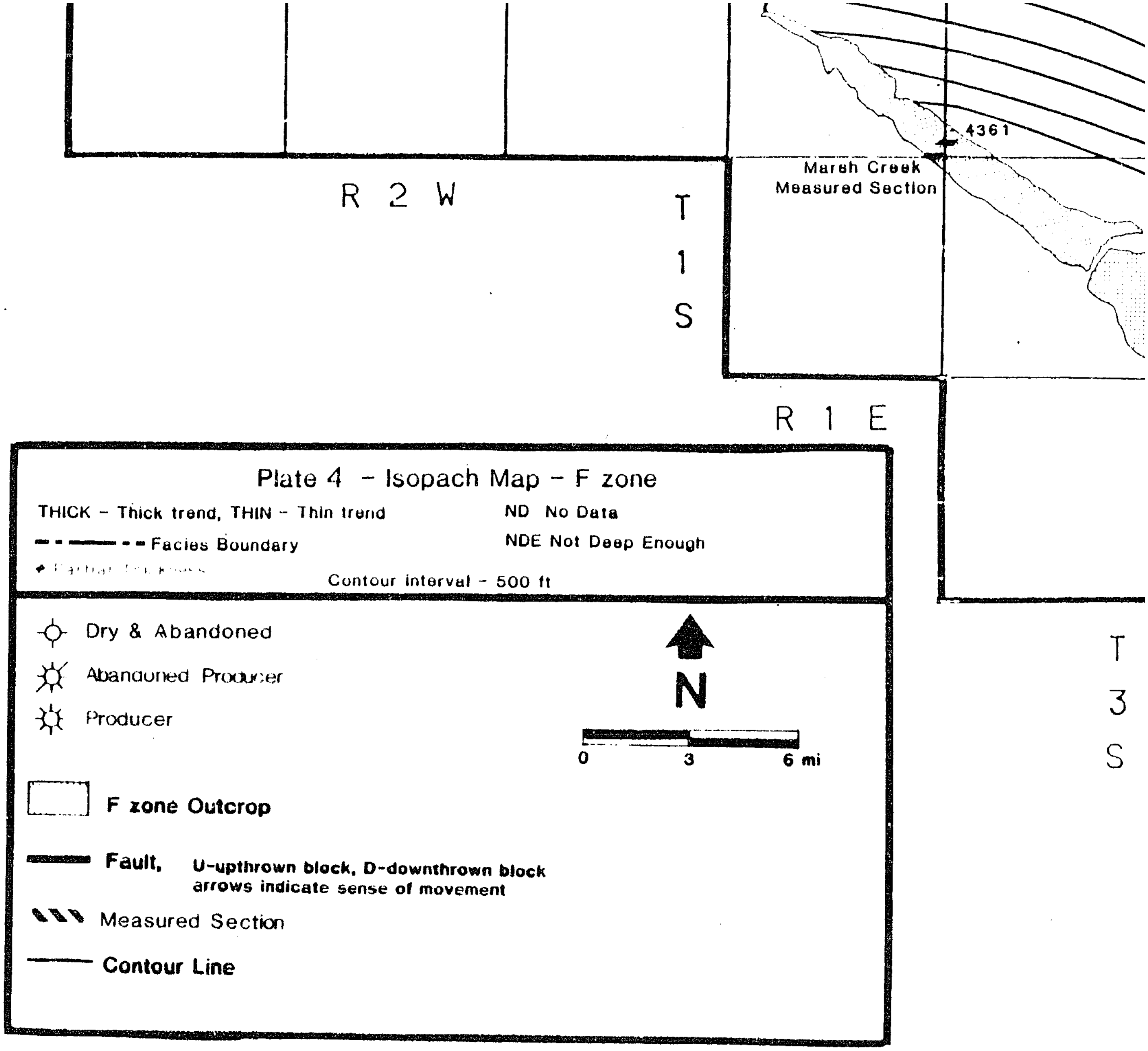

Forbes
Formation
4500
3115
4000
Gates Canyon
Measured Section
3942
T
6
N
3500
3080
3105
3000
ND
2625
495
127
T
4
N
2500
ND
Partially Truncated by Post-Cretaceous Unconformity
2000
T
2
N
4361
Marsh Creek
Measured Section
R 2 W
T
1

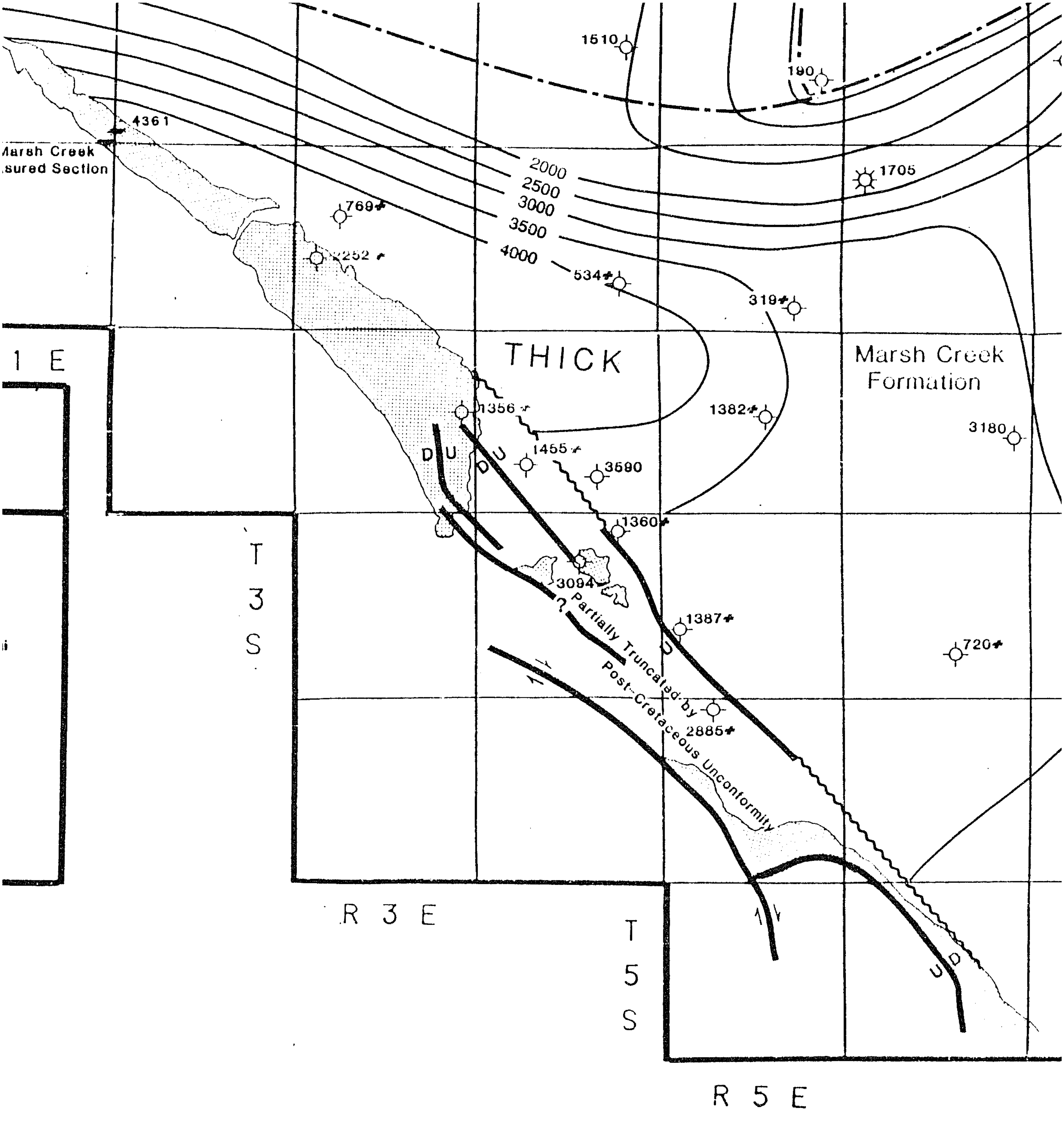


Forbes Formation
Chico Formation
Marsh Creek Measured Section
500
4000
3500
3000
2500
2000
1500
1000
500
2000
2500
3000
3500
ND
NDE
13633+
3460
3115+
2311+
1505
2430
2185
2225
1646+
763
715
380
510
310
440
550
445
310
580
365
640
505
230
200
280
175
160
315
497
125
220
1915
145
350
1860
675
1426+
135
145
460
170
480
215
495+
127+
2218+
2128+
200
1510
190
4361
1705
769+

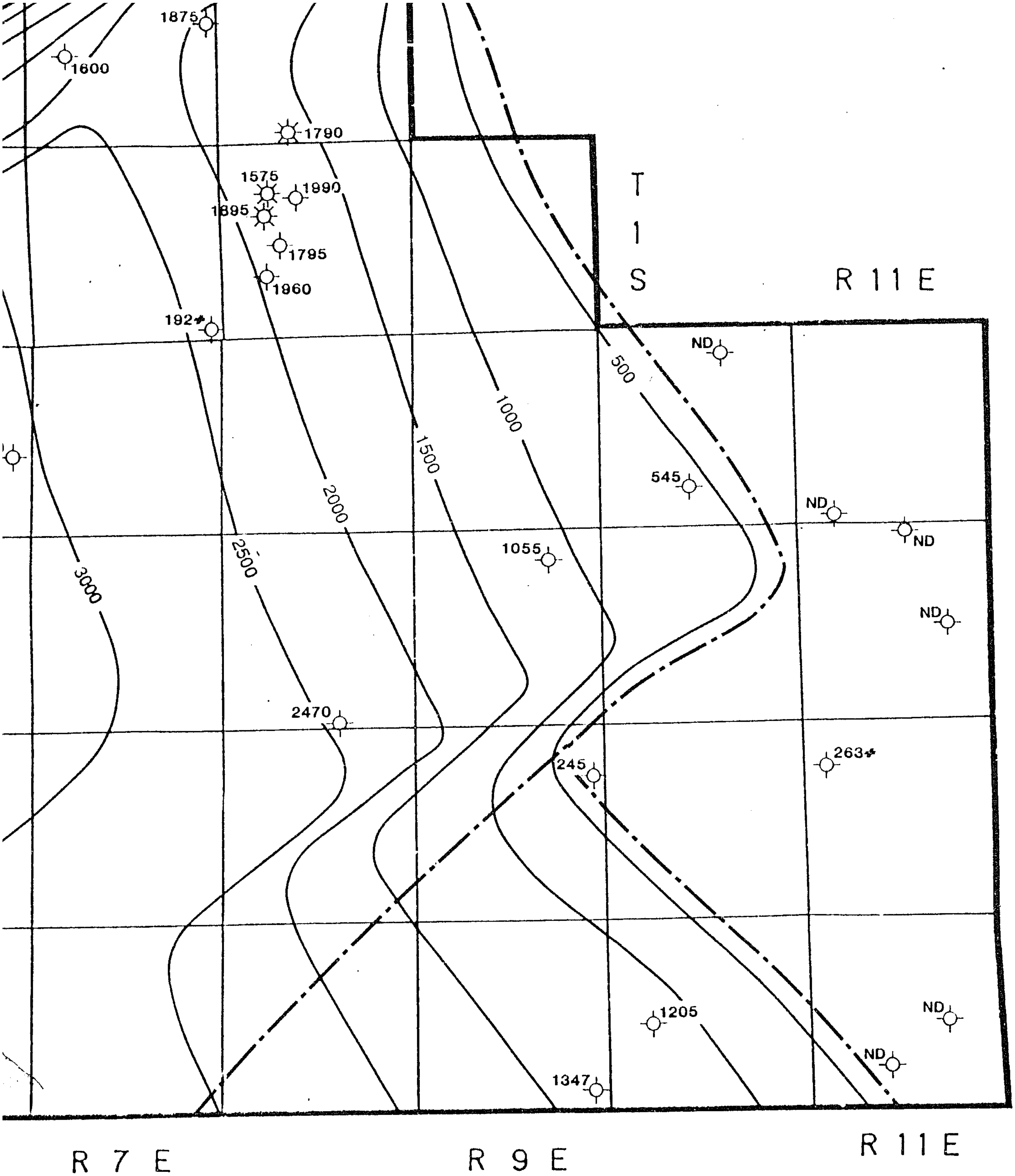


135
125
120
105
140
T
6
N
Chico
ormation
165
145
460
95
230
130
480
215
285
225
160
205
T
4
N
200
205
160
185
110
165
190
215
235
T
2
N
245
2145
1590
2325
1875
1600
1790
1705
1575
1990
1895
T
1


4361
Marsh Creek
Measured Section
R 2 W
T 1 S
R 1 E
T 3 S
Plate 4 - Isopach Map - F zone
THICK - Thick trend, THIN - Thin trend
ND No Data
Facies Boundary
NDE Not Deep Enough
Contour interval - 500 ft
Dry & Abandoned
Abandoned Producer
Producer
N
0
3
6 mi
F zone Outcrop
Fault, U-upthrown block, D-downthrown block
arrows indicate sense of movement
Measured Section
Contour Line



4361
Marsh Creek
sured Section
1510
190
1705
2000
2500
3000
3500
4000
769
252
534
319
THICK
Marsh Creek
Formation
1 E
1356
1382
3180
1455
3590
D U
D U
1360
T
3
S
3094
Partially Truncated by
Post-Cretaceous Unconformity
1387
720
2885
R 3 E
T
5
S
U D
R 5 E



1875
1600
1790
1575
1990
1895
1795
1960
192
ND
500
1000
1500
2000
2500
3000
545
ND
ND
1055
ND
2470
245
263
1205
ND
ND
1347
T 1 S
R 11 E
T 3 S
T 5 S
R 7 E
R 9 E
R 11 E

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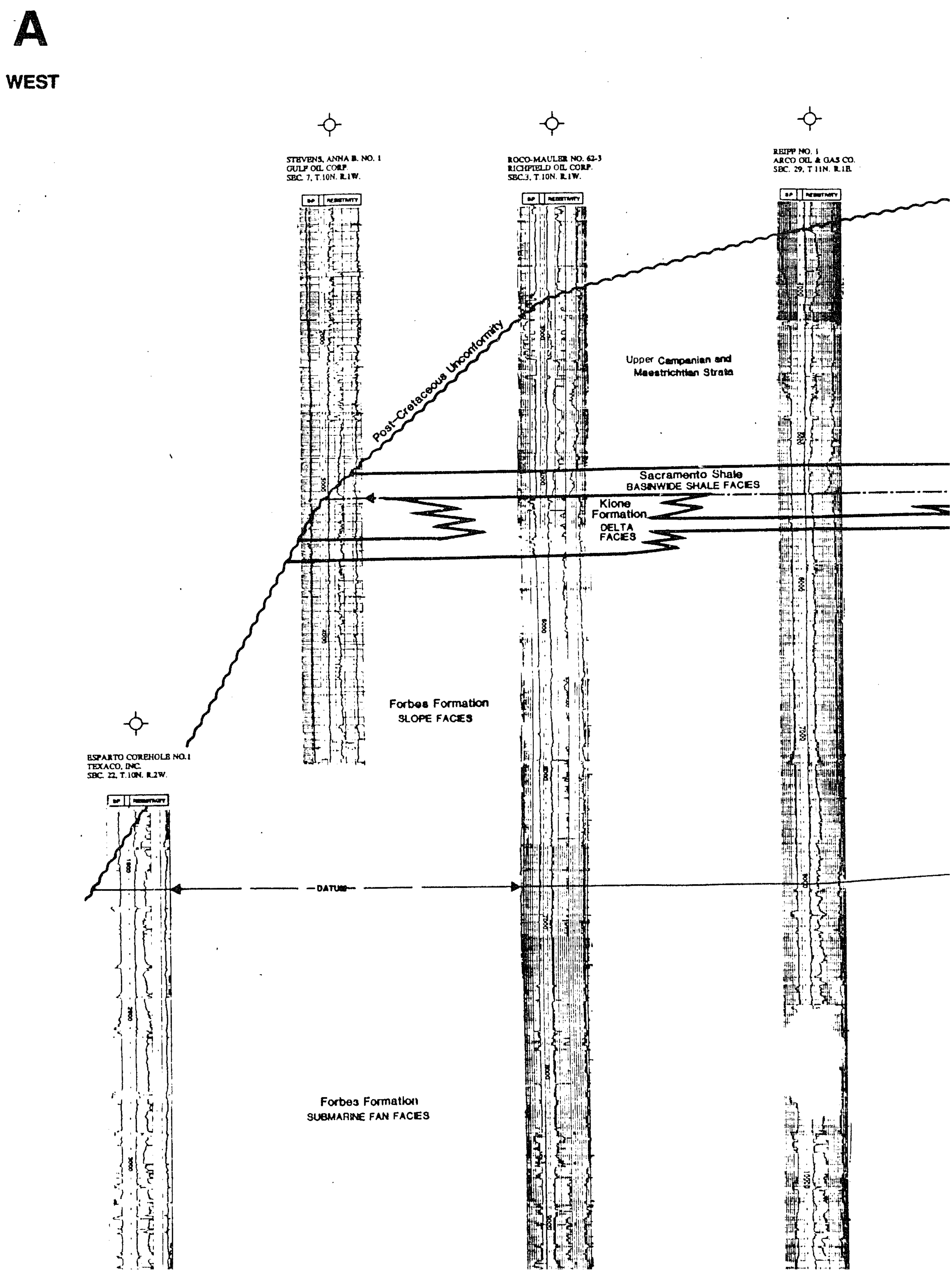
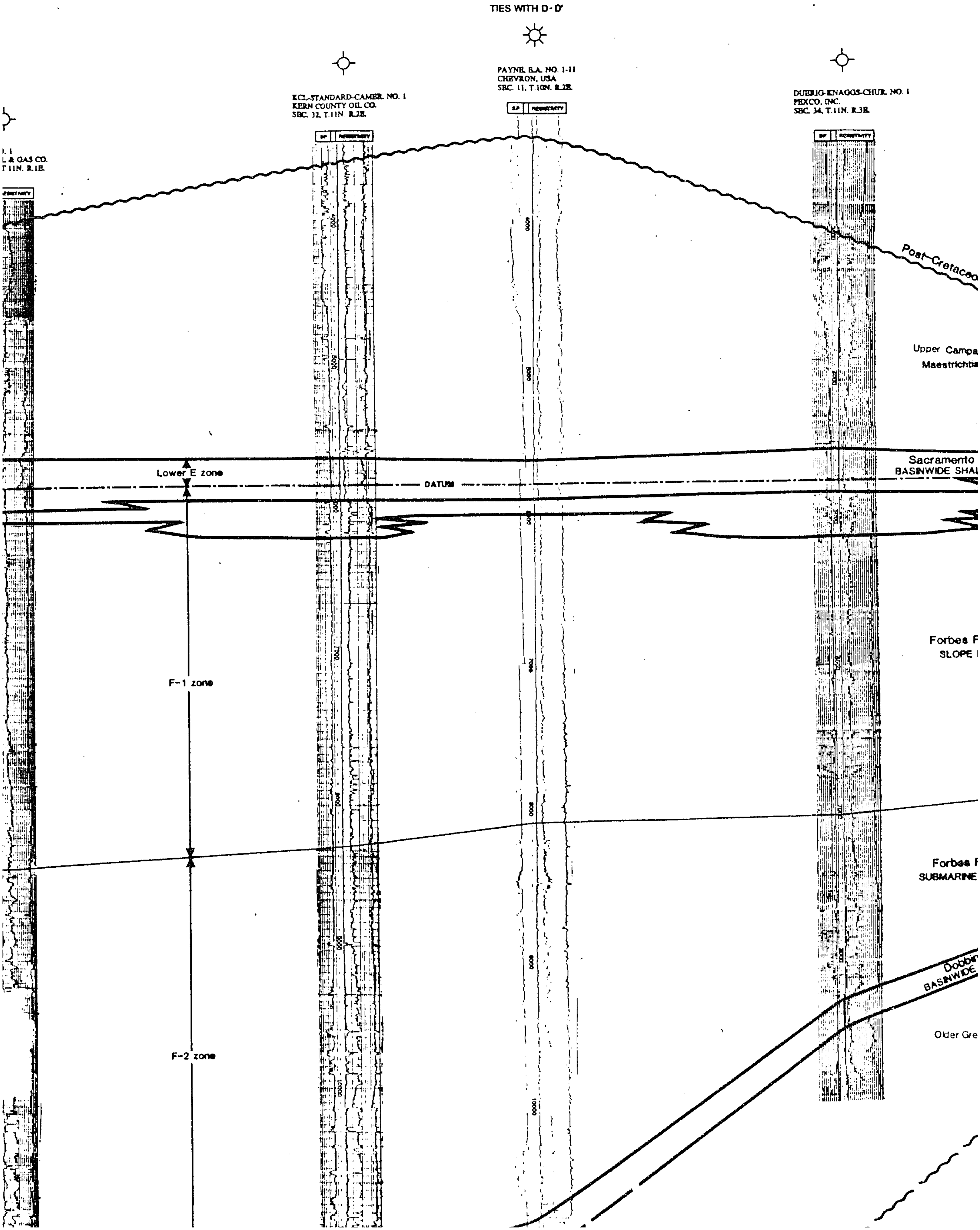


A
WEST
STEVENS, ANNA B. NO. 1
GULF OIL CORP.
SEC. 7, T.10N. R.1W.
ROCO-MAULER NO. 62-3
RICHFIELD OIL CORP.
SEC.3, T.10N. R.1W.
REIPP NO. 1
ARCO OIL & GAS CO.
SEC. 29, T.11N. R.1E.
ESPARTO COREHOLE NO.1
TEXACO, INC.
SEC. 22, T.10N. R.2W.
SP
RESISTIVITY
Post-Cretaceous Unconformity
Upper Campanian and
Maestrichtian Strata
Sacramento Shale
BASINWIDE SHALE FACIES
Kione
Formation
DELTA
FACIES
Forbes Formation
SLOPE FACIES
DATUM
Forbes Formation
SUBMARINE FAN FACIES



TIES WITH D-D'
KCL-STANDARD-CAMER. NO. 1
KERN COUNTY OIL CO.
SEC. 32, T.11N. R.2E.
PAYNE, B.A. NO. 1-11
CHEVRON, USA
SEC. 11, T.10N. R.2E.
DUERIG-KNAGGS-CHUR. NO. 1
PEXCO, INC.
SEC. 34, T.11N. R.3E.
Post-Cretaceo
Upper Campa
Maestrichtia
Lower E zone
DATUM
Sacramento
BASINWIDE SHA
F-1 zone
Forbes F
SLOPE
Forbes F
SUBMARINE
Dobbin
BASINWIDE
Older Gre
F-2 zone

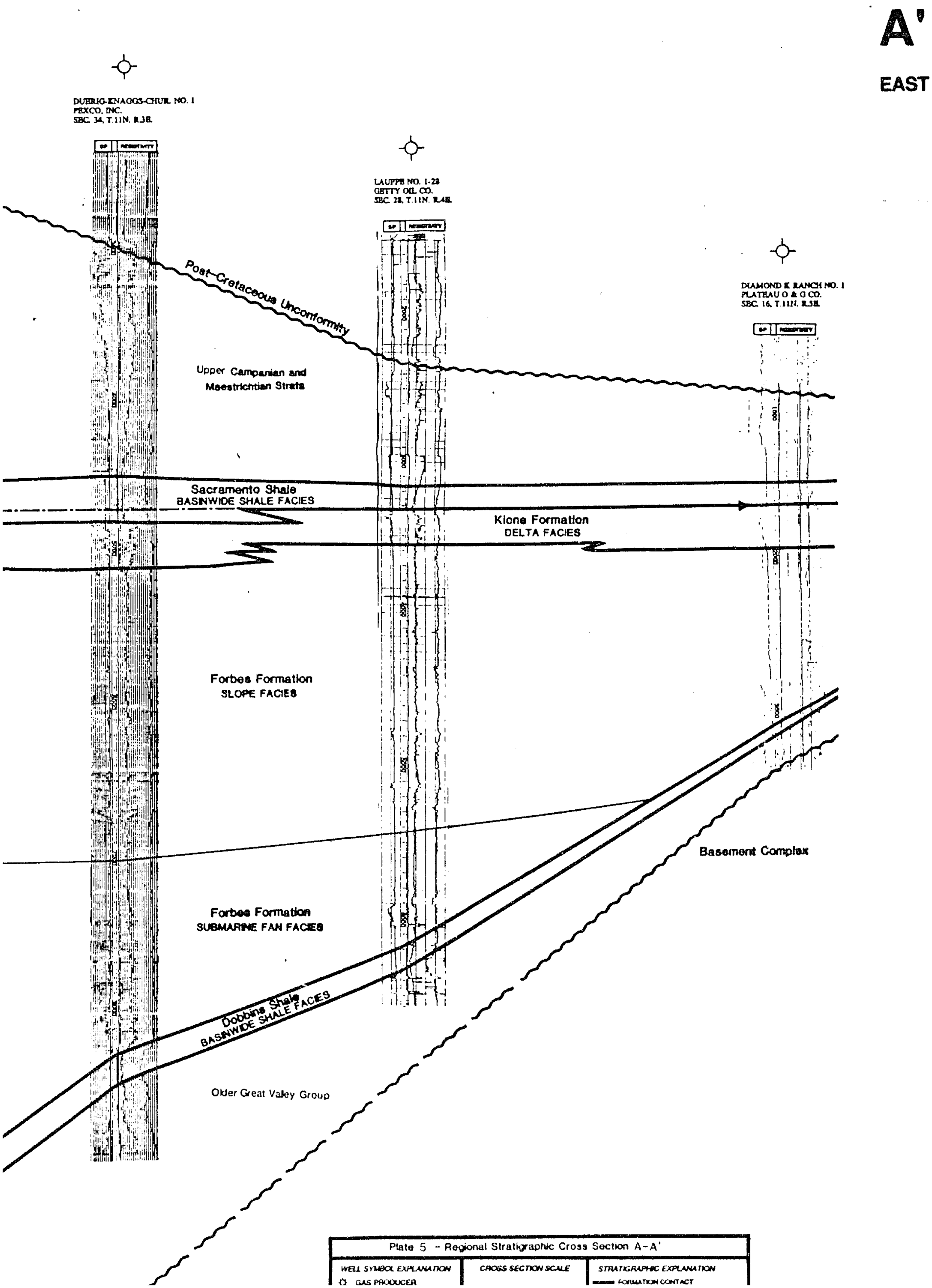
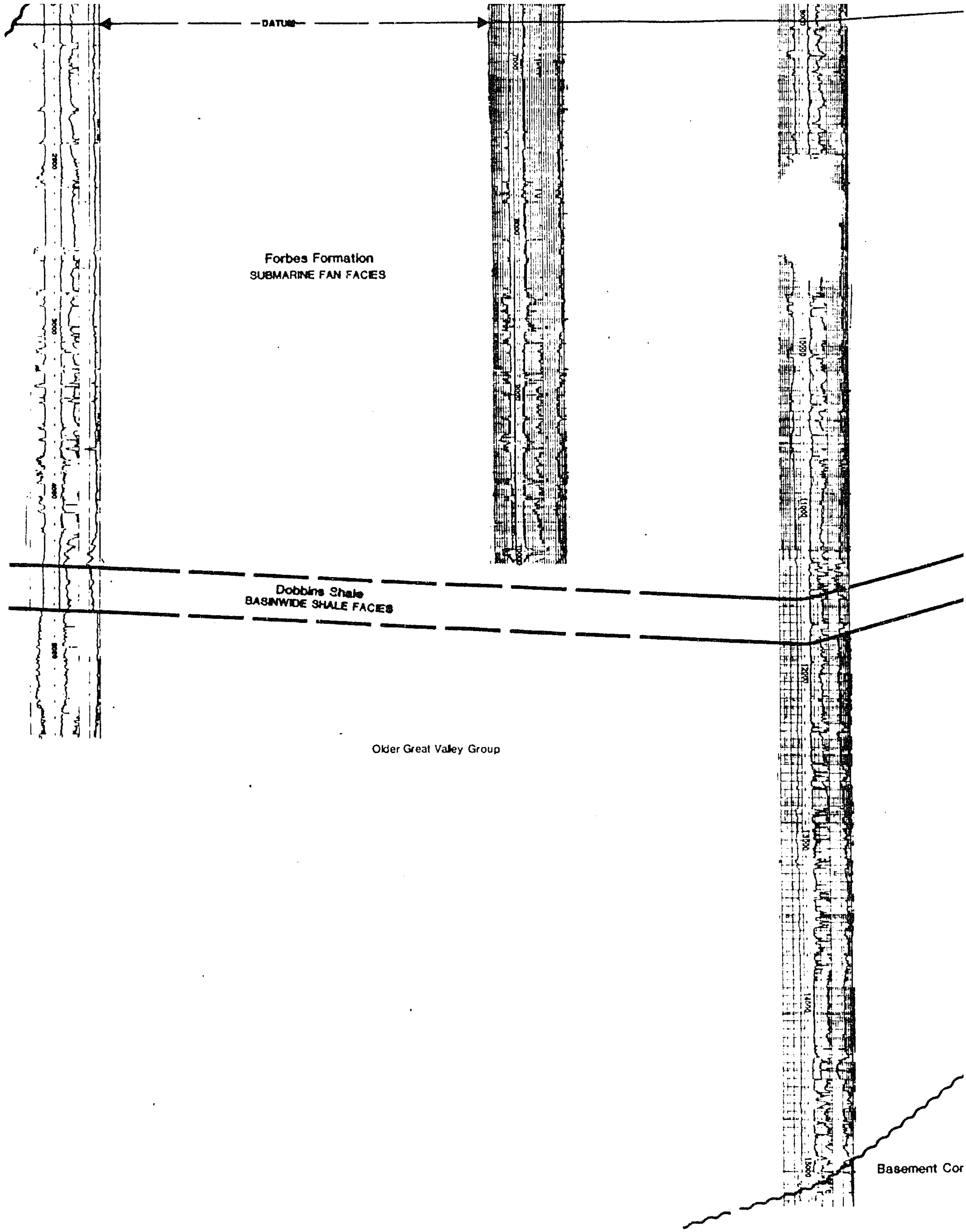
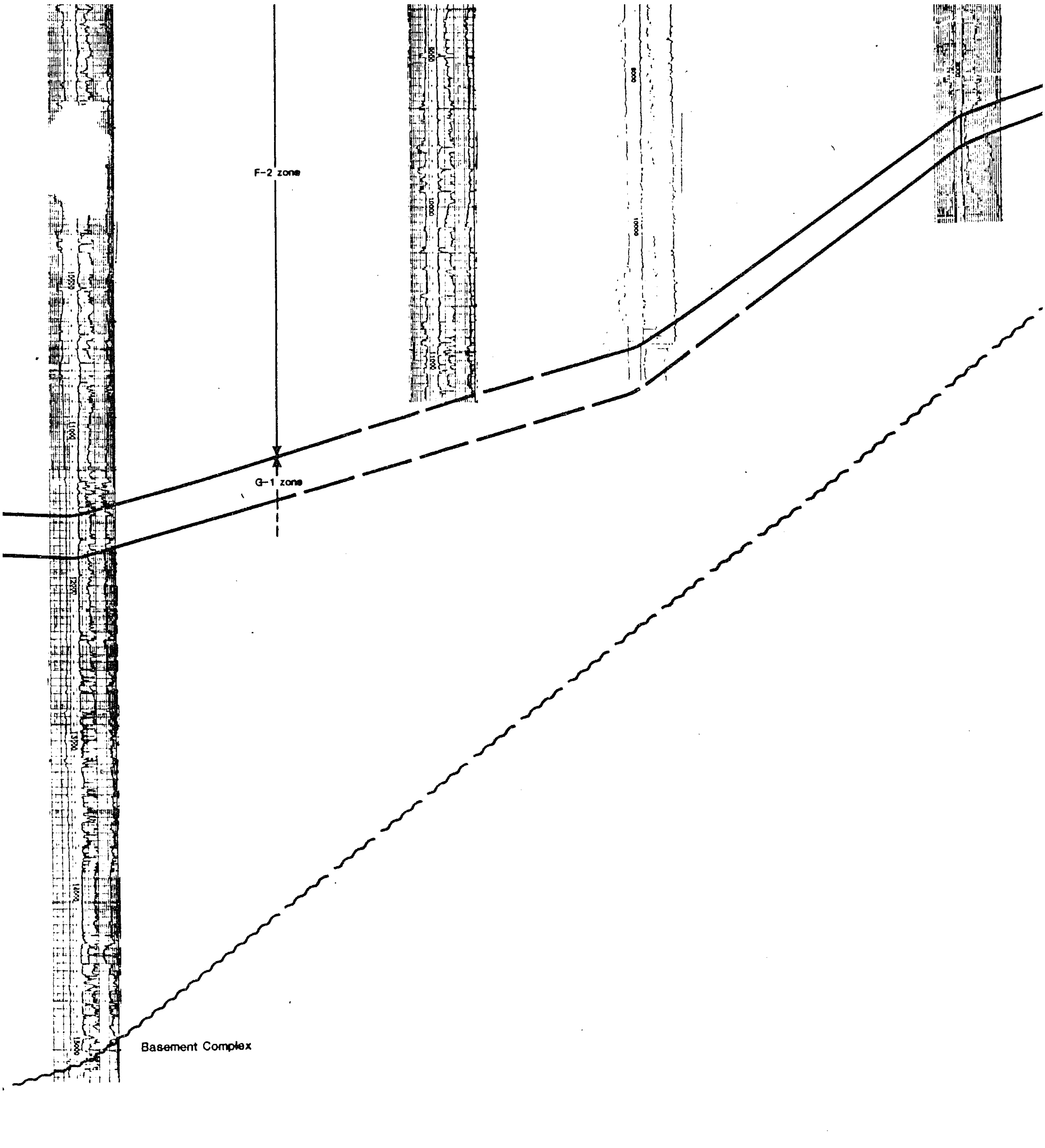
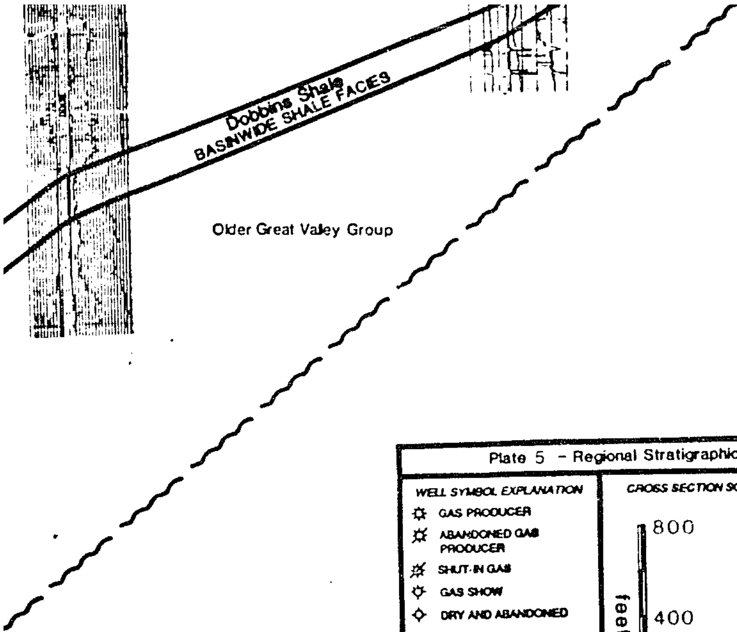


Plate 5 - Regional Stratigraphic Cross Section A-A'		
WELL SYMBOL EXPLANATION	*CROSS SECTION SCALE*	*STRATIGRAPHIC EXPLANATION*
GAS PRODUCER		FORMATION CONTACT


DATUM
Forbes Formation
SUBMARINE FAN FACIES
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Cor


F-2 zone
G-1 zone
Basement Complex


Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group

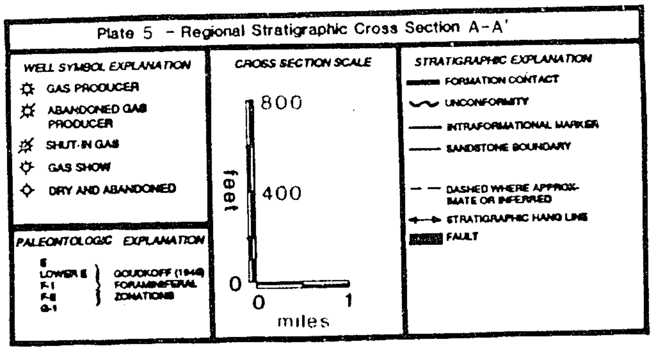
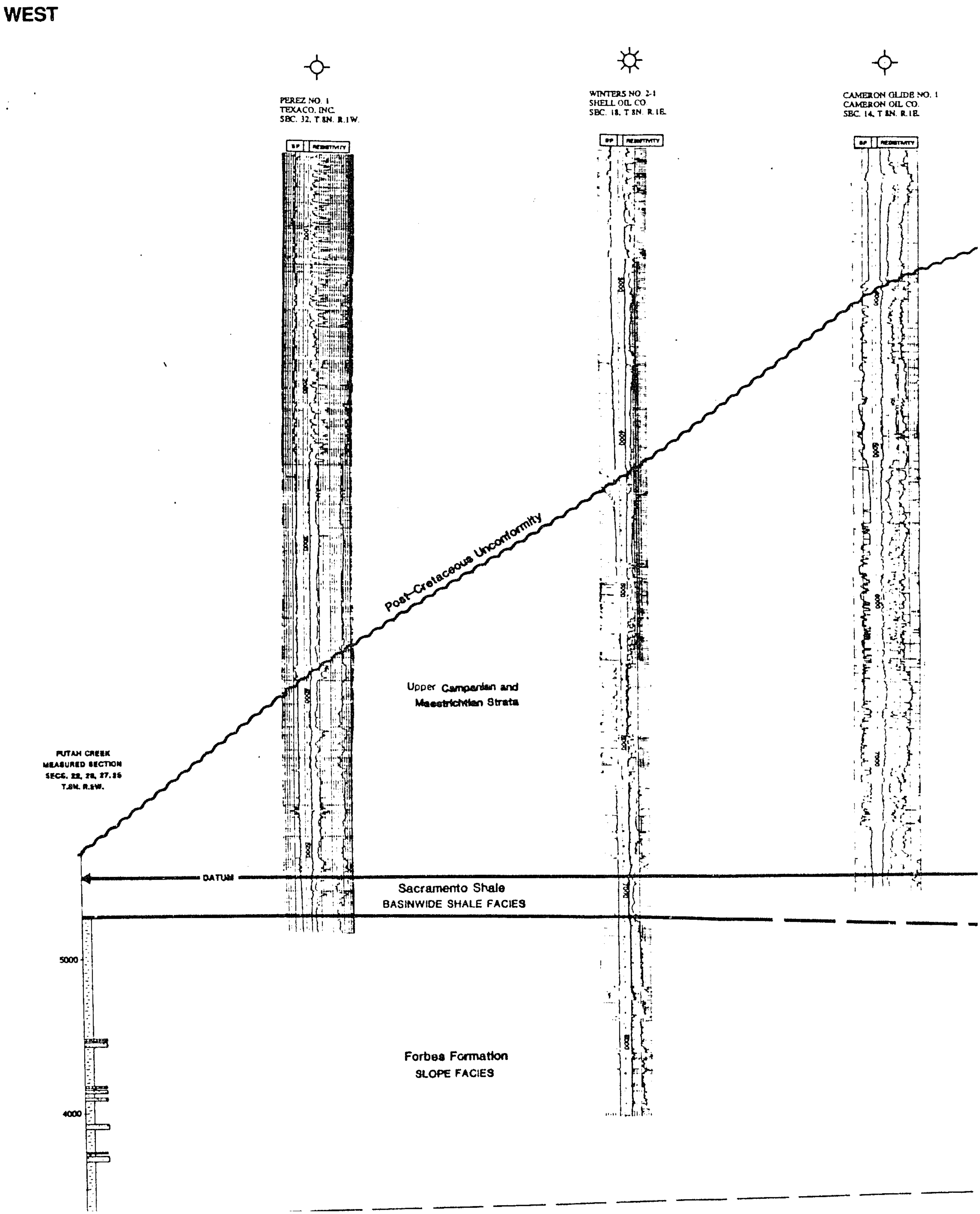
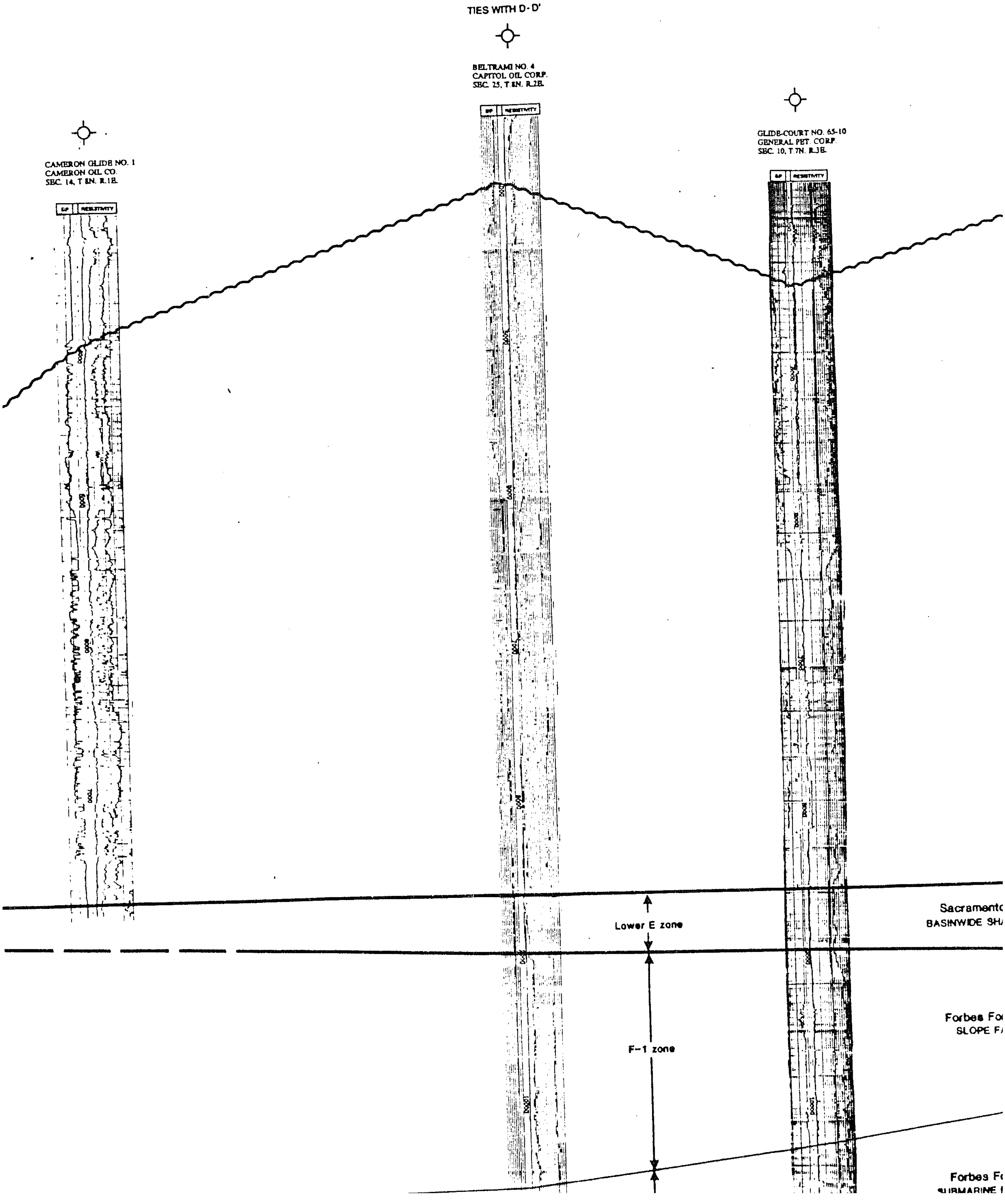
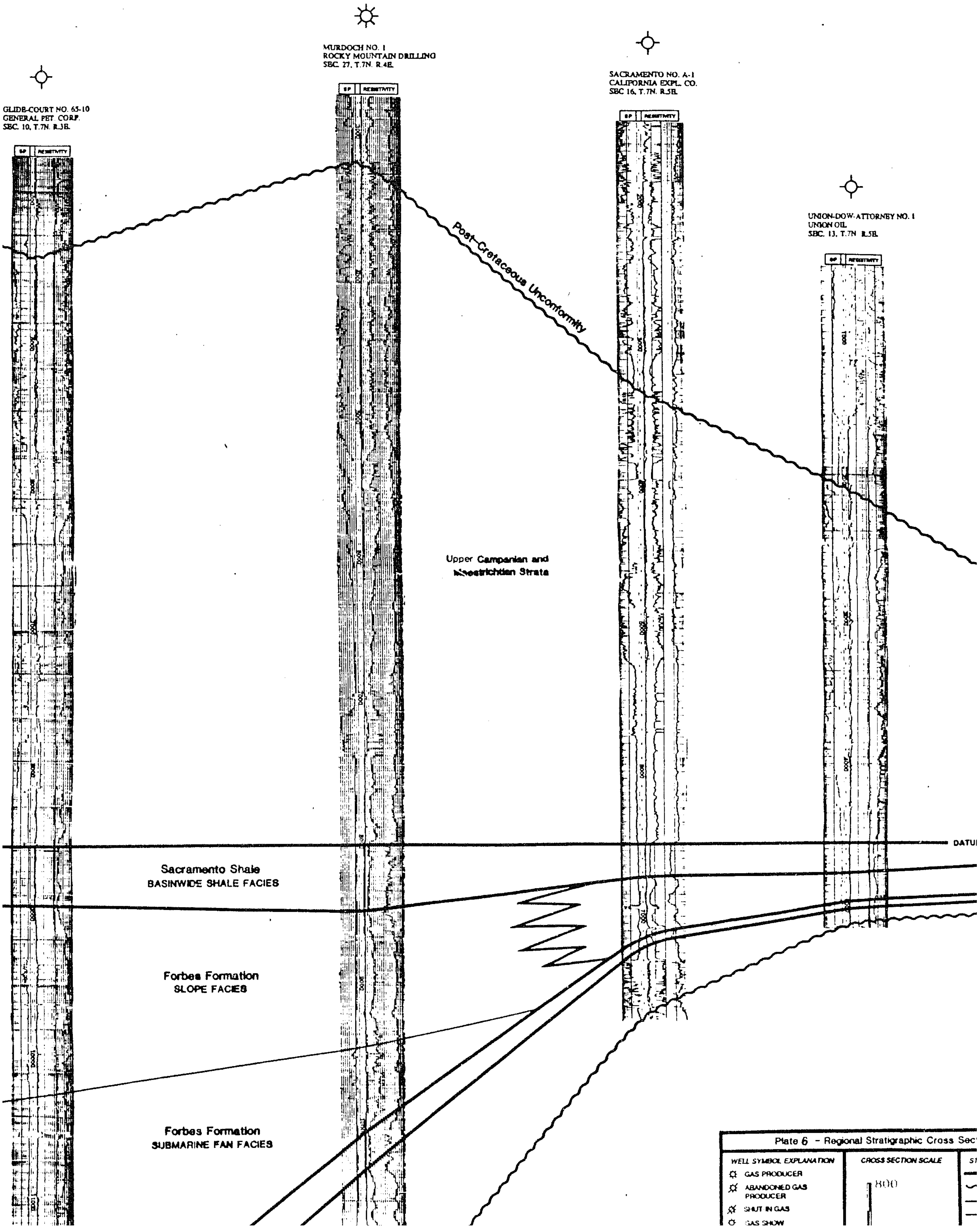


Plate 5 - Regional Stratigraphic Cross Section A-A'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-II
G-1
GOUDKOFF (1944) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT

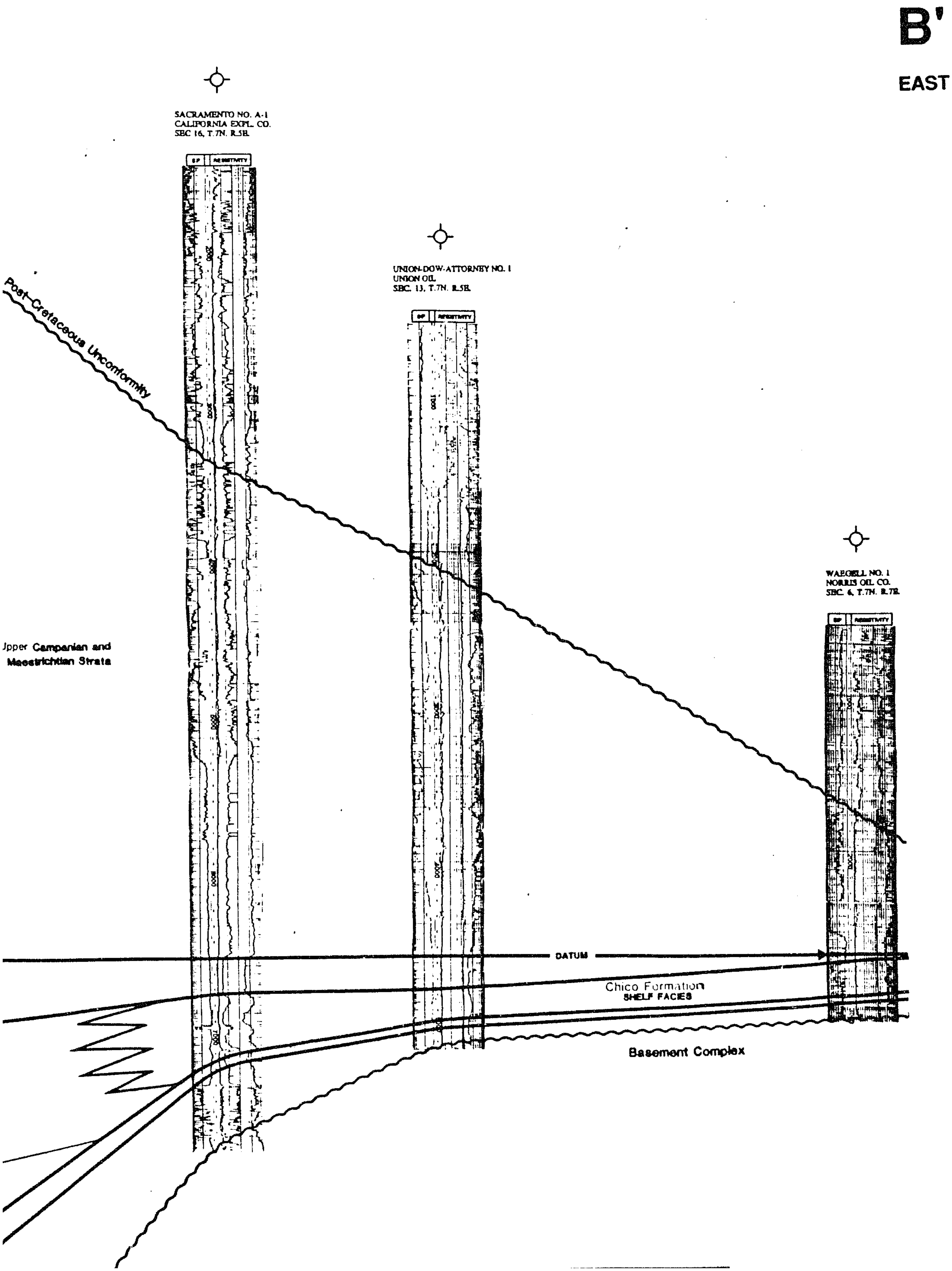
B


WEST
PEREZ NO. 1
TEXACO, INC.
SEC. 32, T.8N. R.1W.
WINTERS NO. 2-1
SHELL OIL CO.
SEC. 18, T.8N. R.1E.
CAMERON GLIDE NO. 1
CAMERON OIL CO.
SEC. 14, T.8N. R.1E.
SP
RESISTIVITY
Post-Cretaceous Unconformity
Upper Campanian and
Maestrichtian Strata
PUTAH CREEK
MEASURED SECTION
DATUM
Sacramento Shale
BASINWIDE SHALE FACIES
Forbes Formation
SLOPE FACIES
5000
4000

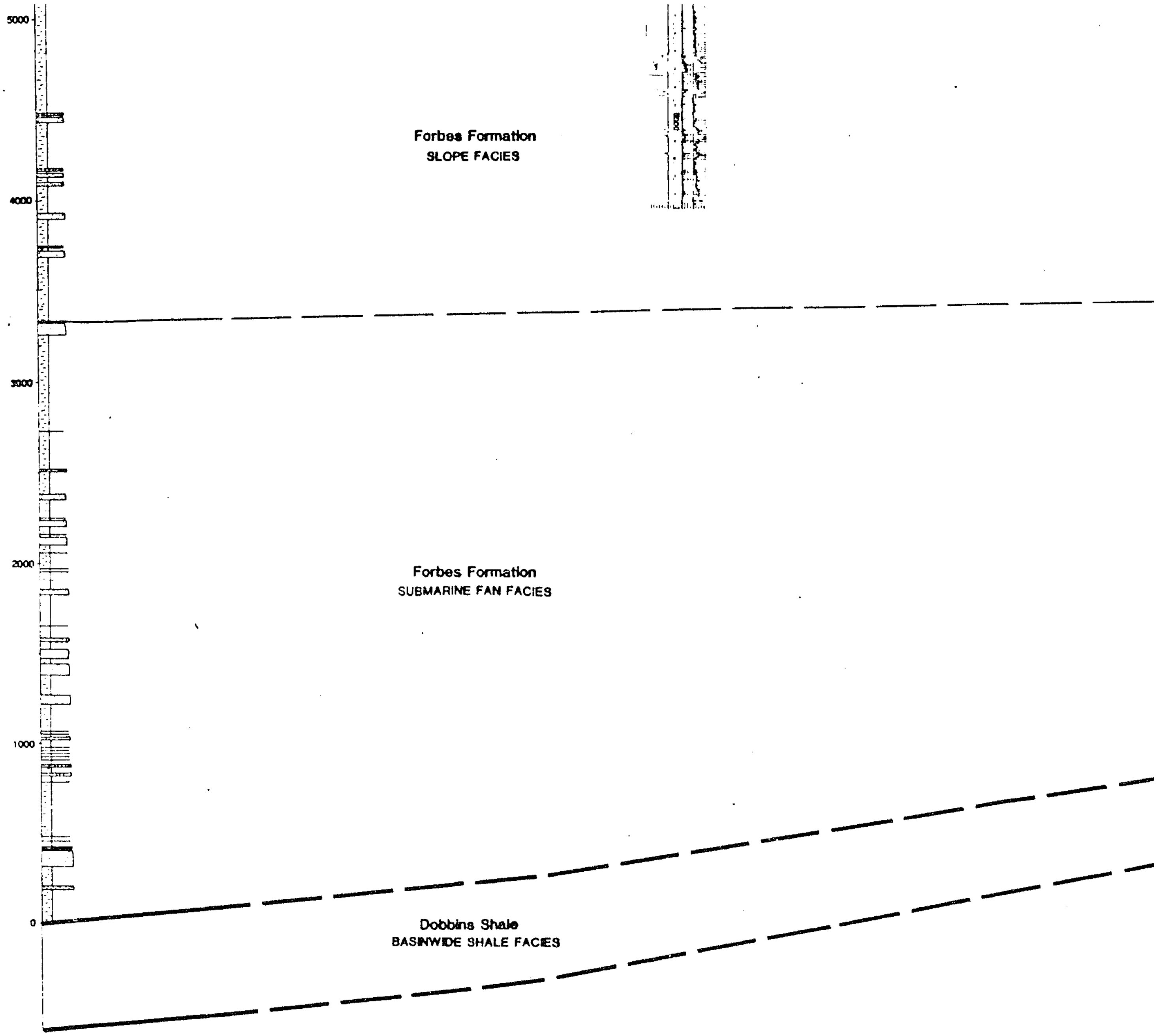

TIES WITH D-D'
BELTRAMI NO. 4
CAPITOL OIL CORP.
SEC. 25, T 8N. R.2E.
CAMERON GLIDE NO. 1
CAMERON OIL CO.
SEC. 14, T 8N. R.1E.
GLIDE-COURT NO. 65-10
GENERAL PET. CORP.
SEC. 10, T 7N. R.3E.
SP
RESISTIVITY
Lower E zone
F-1 zone
Sacramento
BASINWIDE SH
Forbes Fo
SLOPE F
Forbes Fo
SUBMARINE



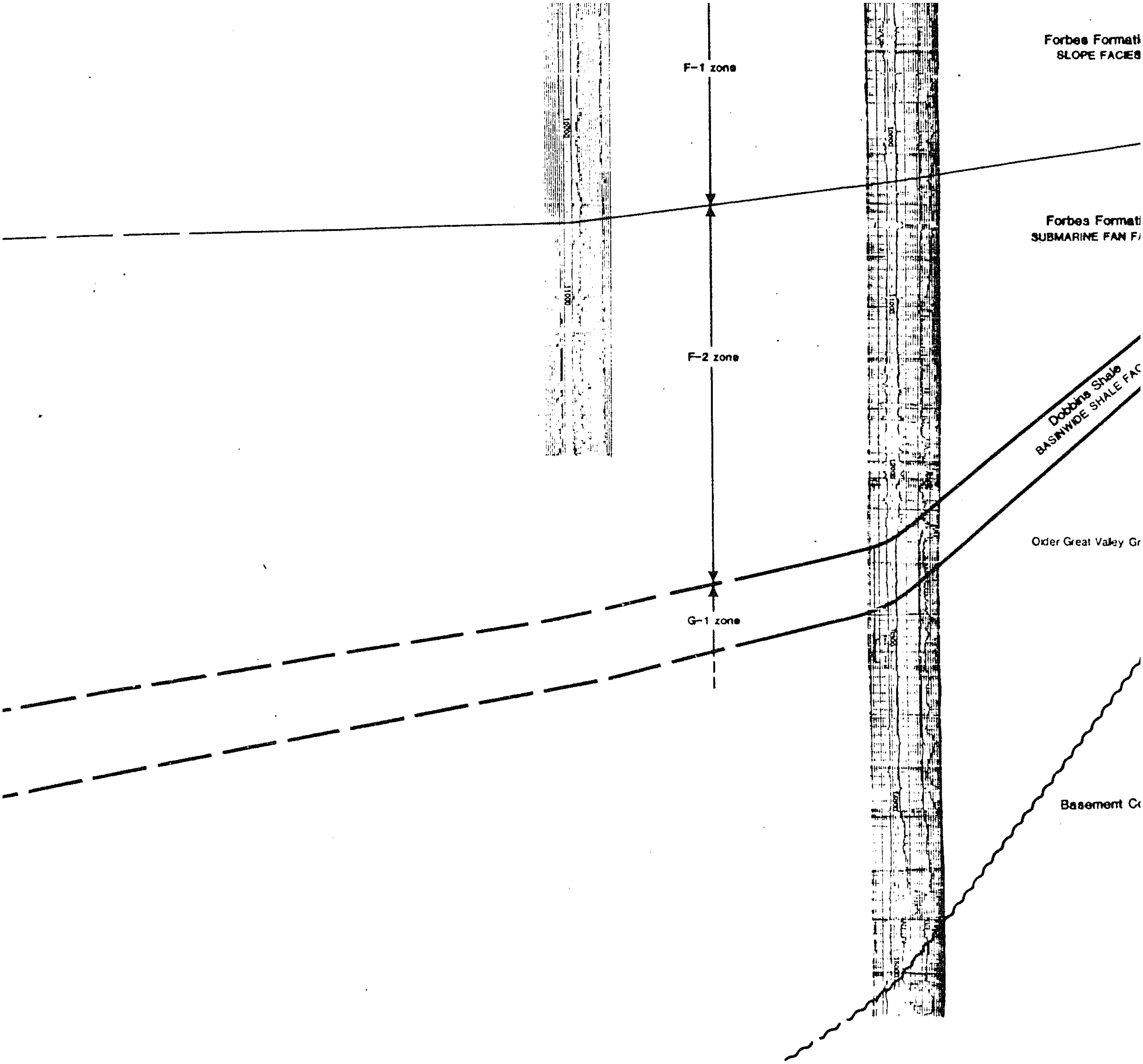
MURDOCH NO. 1
ROCKY MOUNTAIN DRILLING
SEC. 27, T.7N. R.4E.
SACRAMENTO NO. A-1
CALIFORNIA EXPL. CO.
SEC 16, T.7N. R.5E.
GLIDE-COURT NO. 65-10
GENERAL PET. CORP.
SEC. 10, T.7N. R.3E.
UNION-DOW-ATTORNEY NO. 1
UNION OIL
SEC. 13, T.7N R.5E.
SP
RESISTIVITY
Post-Cretaceous Unconformity
Upper Campanian and
Maestrichtian Strata
DATU
Sacramento Shale
BASINWIDE SHALE FACIES
Forbes Formation
SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES
Plate 6 - Regional Stratigraphic Cross Sec
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT IN GAS
GAS SHOW
CROSS SECTION SCALE
800

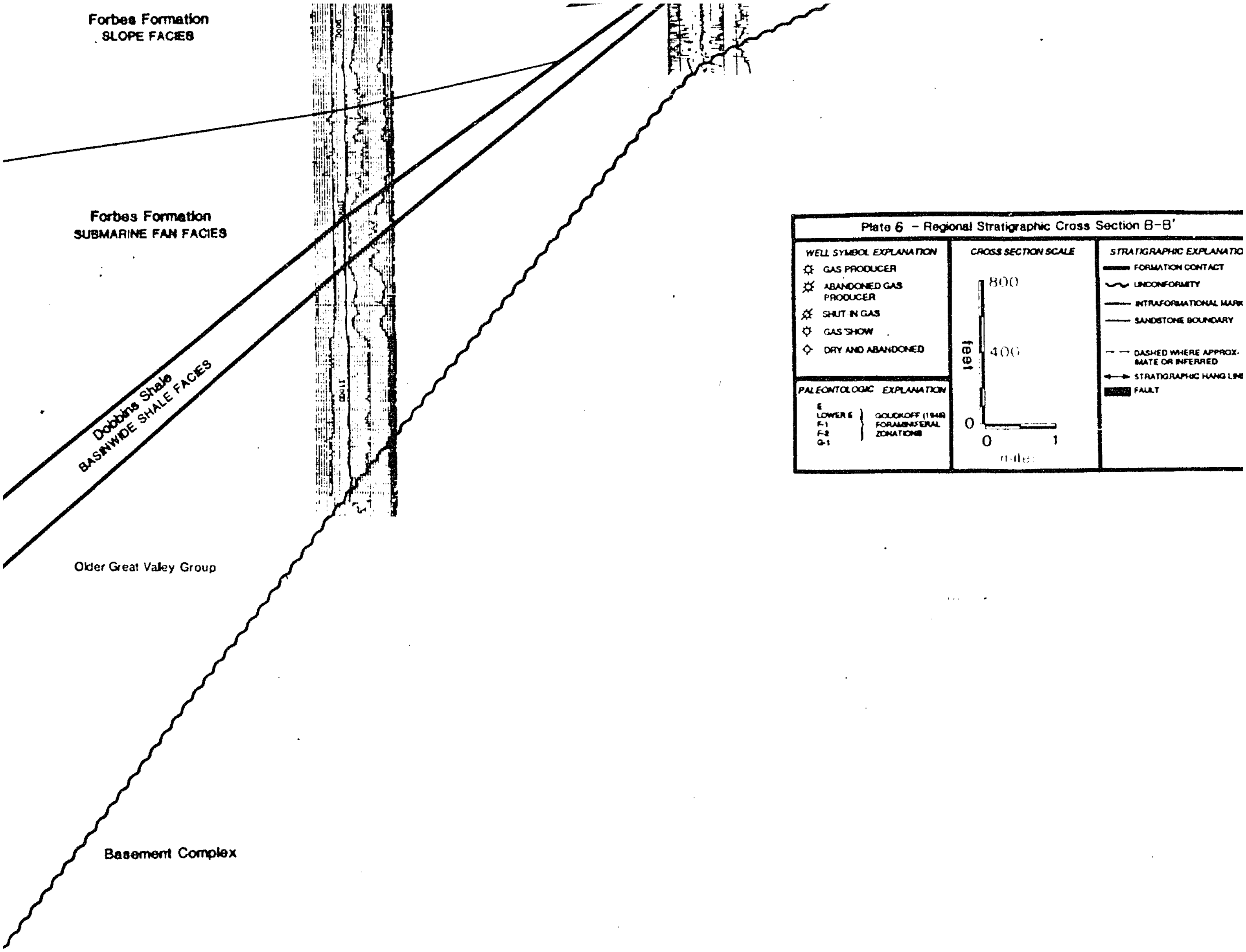


B'
EAST
SACRAMENTO NO. A-1
CALIFORNIA EXPL. CO.
SEC 16, T.7N. R.5E.
UNION-DOW-ATTORNEY NO. 1
UNION OIL
SEC. 13, T.7N. R.5E.
WAEGELL NO. 1
NORRIS OIL CO.
SEC. 6, T.7N. R.7E.
Post-Cretaceous Unconformity
Jpper Campanian and
Maestrichtian Strata
DATUM
Chico Formation
SHELF FACIES
Basement Complex

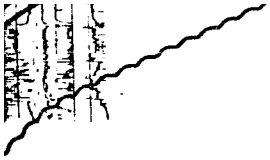


5000
4000
3000
2000
1000
0
Forbes Formation
SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES
Dobbins Shale
BASINWIDE SHALE FACIES


Forbes Formati
SLOPE FACIES
F–1 zone
Forbes Formati
SUBMARINE FAN F/
F–2 zone
Dobbins Shale
BASINWIDE SHALE FAC
Older Great Valley Gr
G–1 zone
Basement Co



Forbes Formation
SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Complex
Plate 6 - Regional Stratigraphic Cross Section B-B'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATIO
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARK
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT



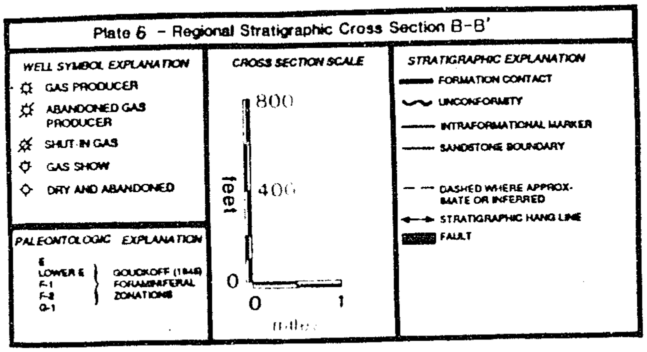


Plate 6 - Regional Stratigraphic Cross Section B-B'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT

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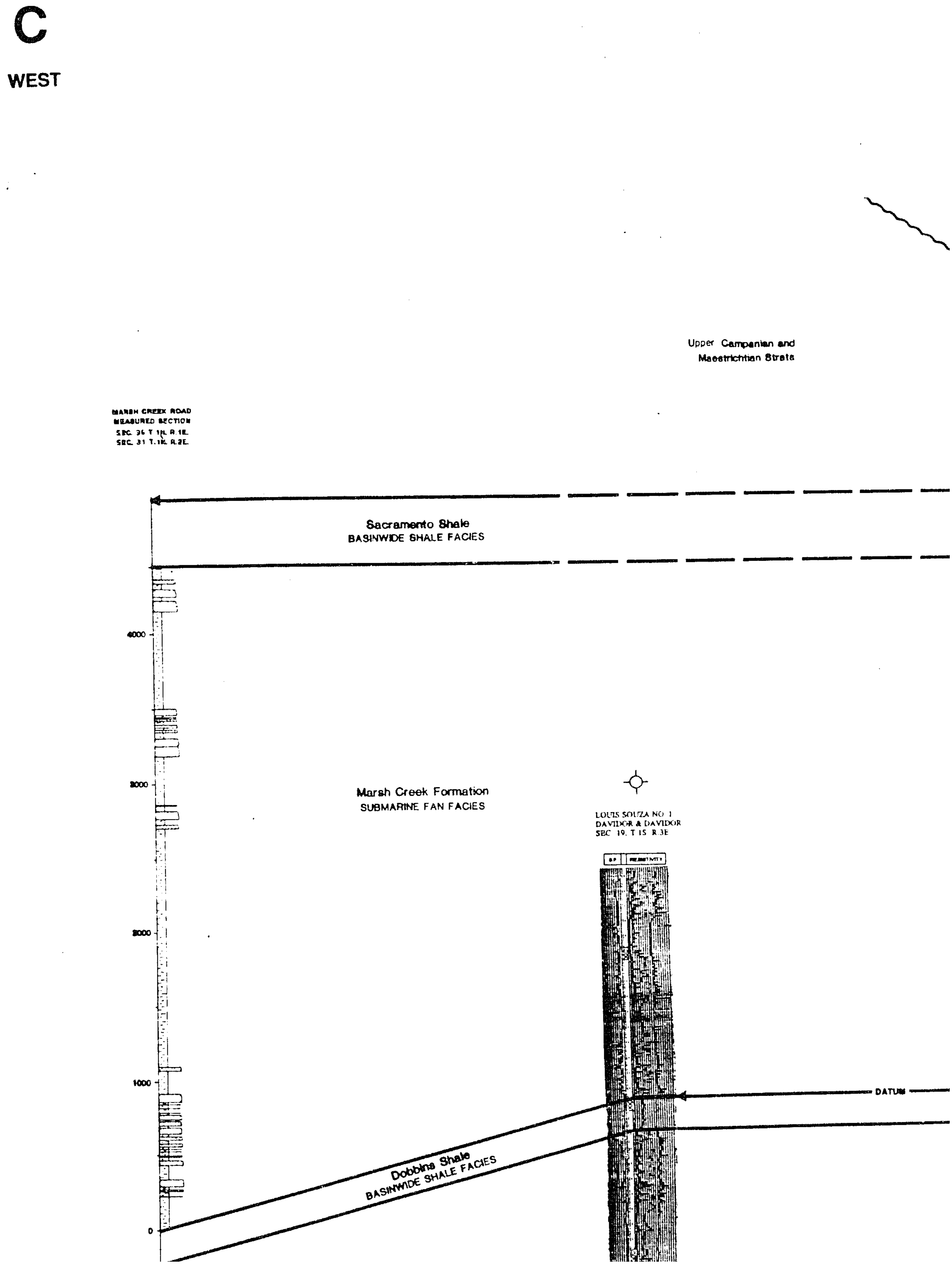
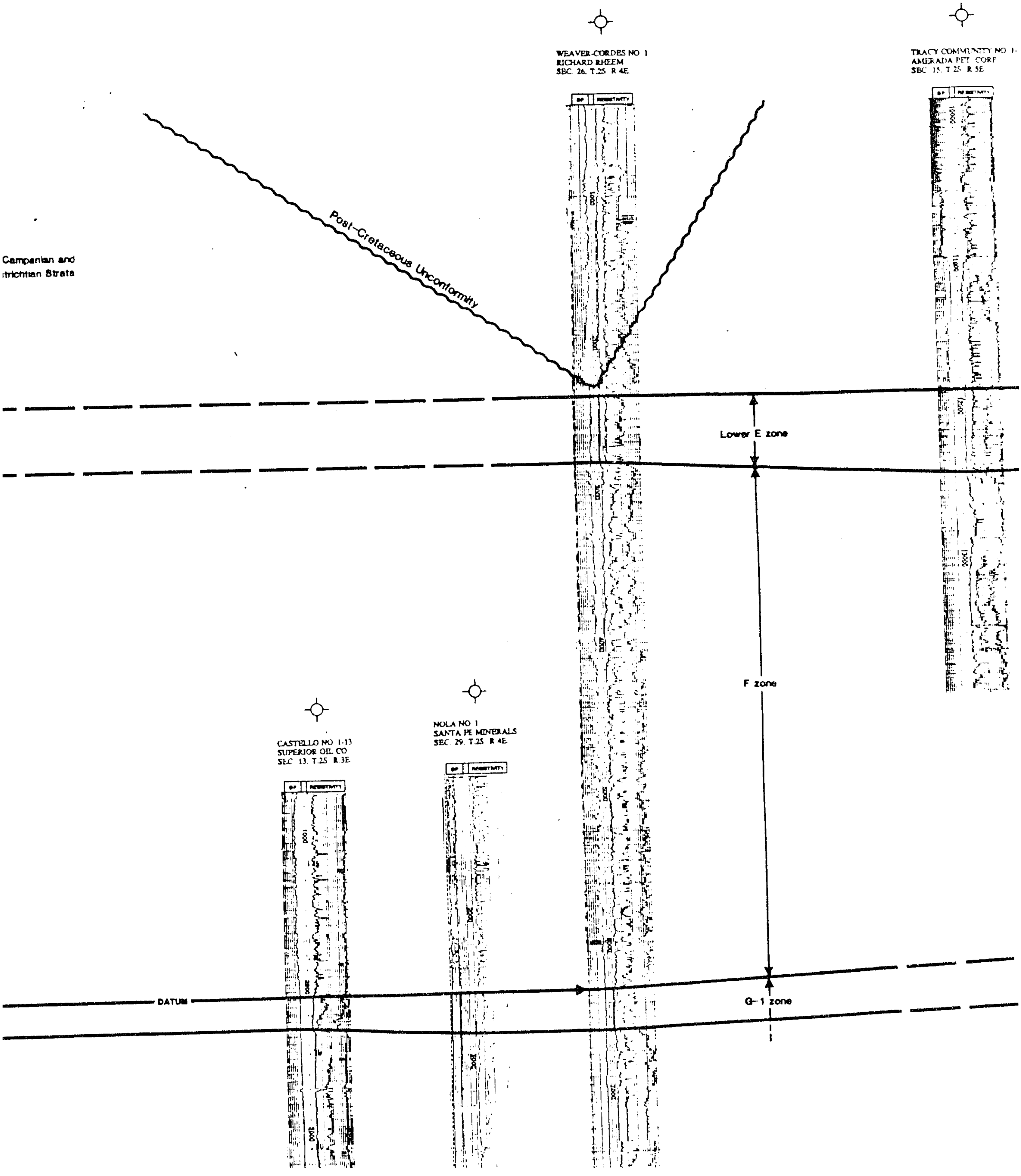

C
WEST
Upper Campanian and
Maestrichtian Strata
MARSH CREEK ROAD
MEASURED SECTION
SEC. 36 T 1N. R.1E.
SEC. 31 T.1N. R.2E.
Sacramento Shale
BASINWIDE SHALE FACIES
4000
3000
Marsh Creek Formation
SUBMARINE FAN FACIES
LOUIS SOUZA NO. 1
DAVIDOR & DAVIDOR
SEC 19, T 1S R.3E
SP
RESISTIVITY
2000
1000
DATUM
Dobbins Shale
BASINWIDE SHALE FACIES
0



WEAVER-CORDES NO. 1
RICHARD RHEEM
SEC. 26, T.2S, R.4E.
TRACY COMMUNITY NO. 1-
AMERADA PET. CORP.
SEC. 15, T.2S, R.5E.
Campanian and
itrichtian Strata
Post-Cretaceous Unconformity
Lower E zone
F zone
CASTELLO NO. 1-13
SUPERIOR OIL CO.
SEC. 13, T.2S, R.3E.
NOLA NO. 1
SANTA FE MINERALS
SEC. 29, T.2S, R.4E.
DATUM
G-1 zone

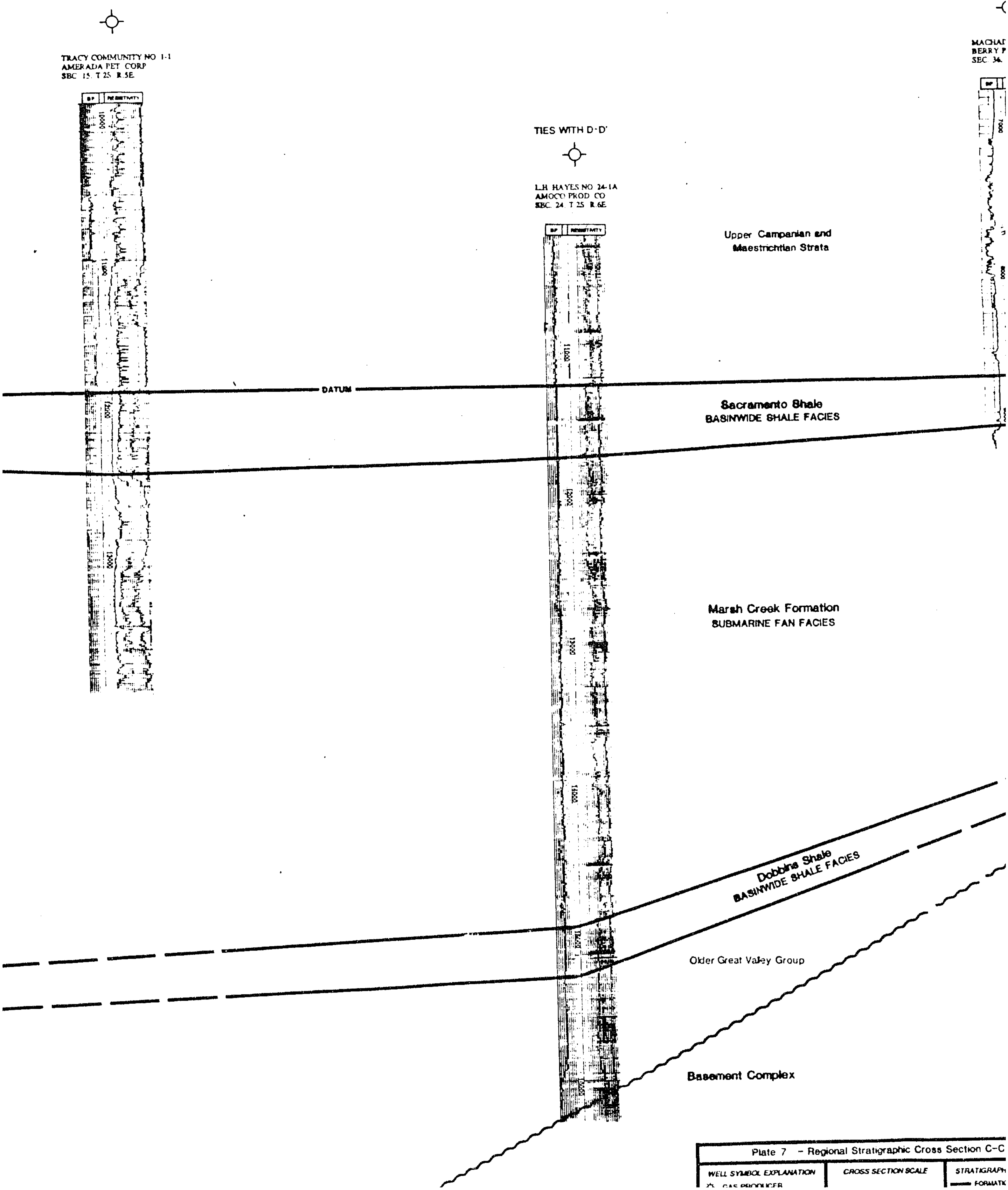
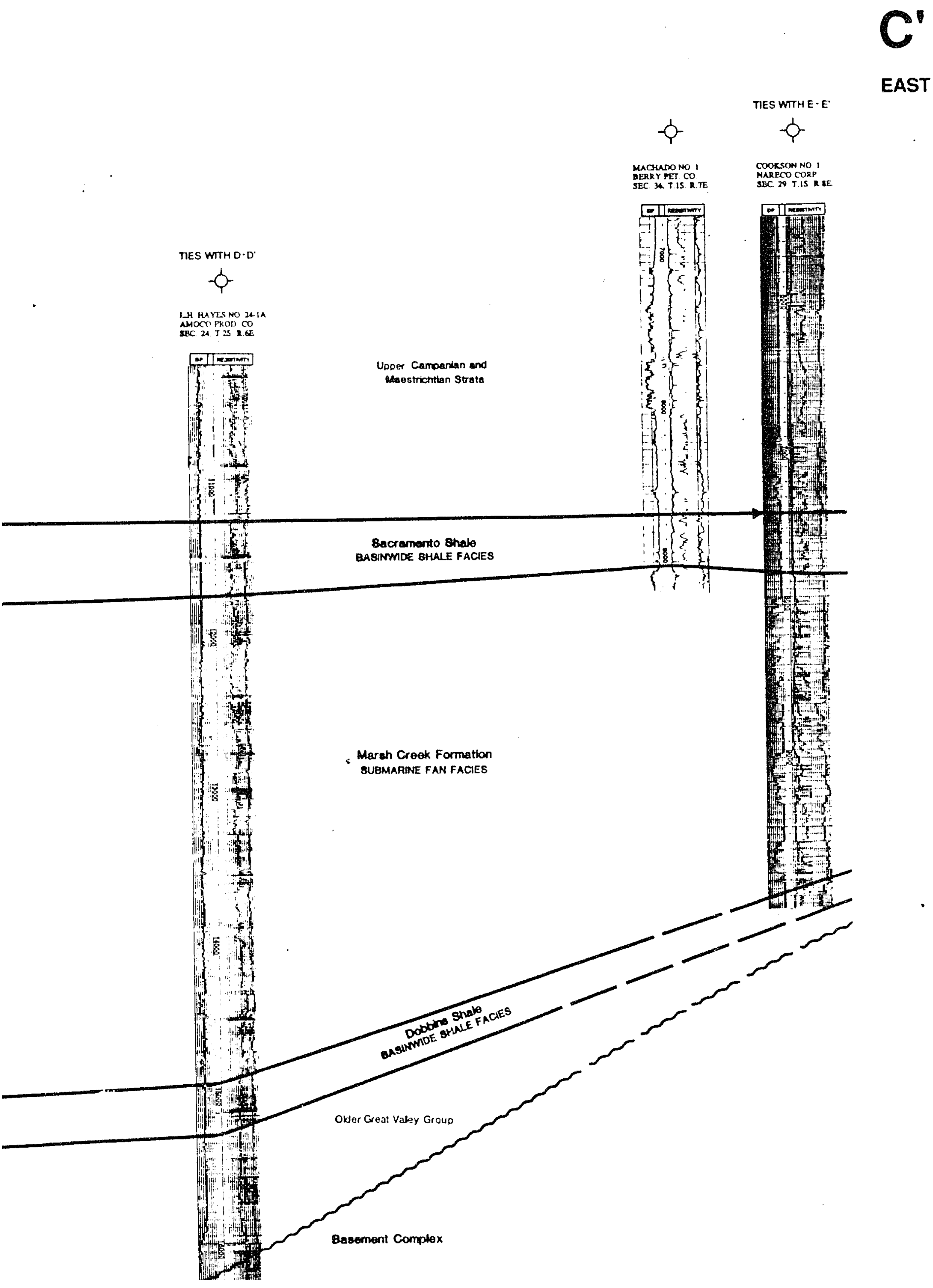
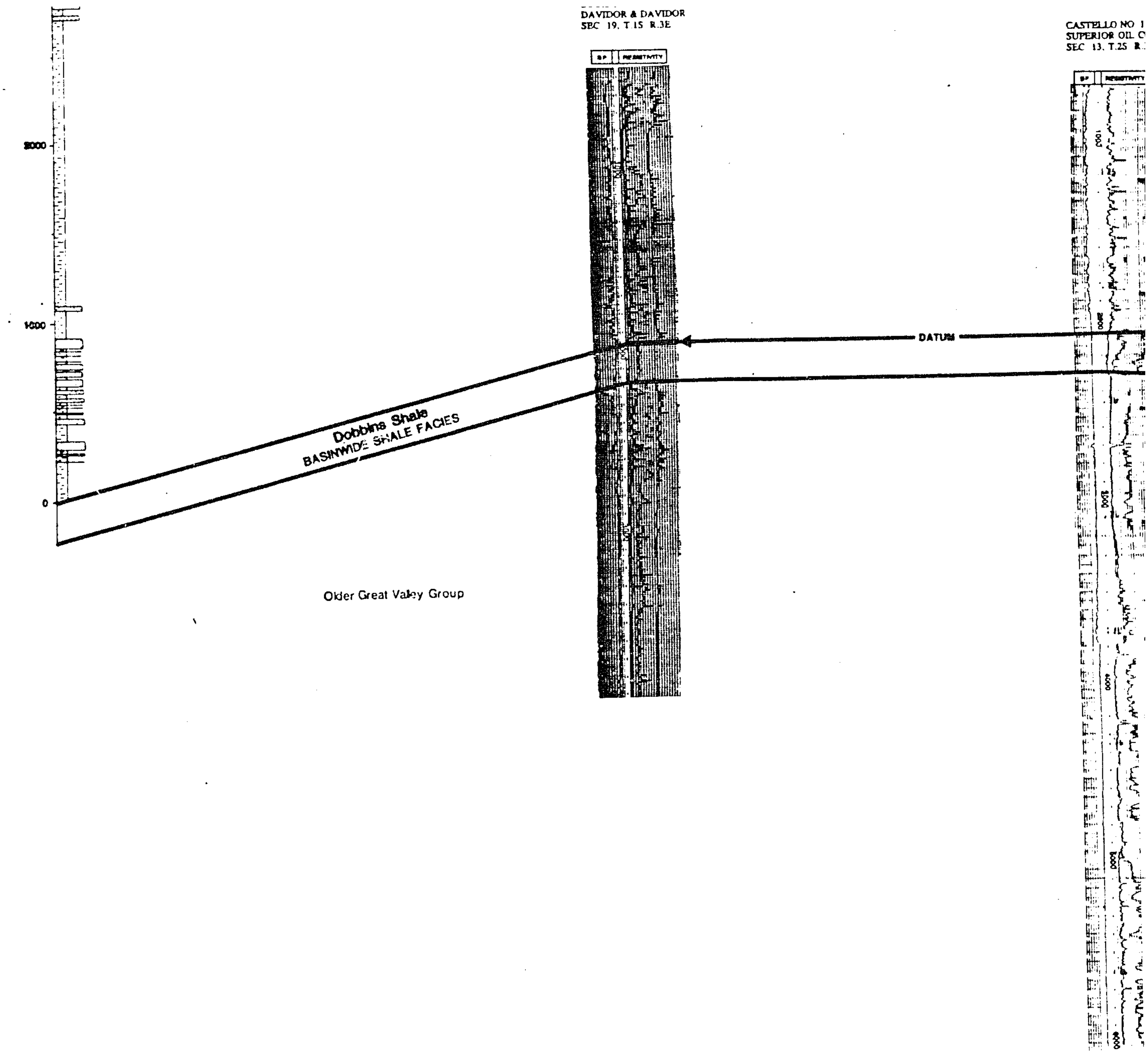
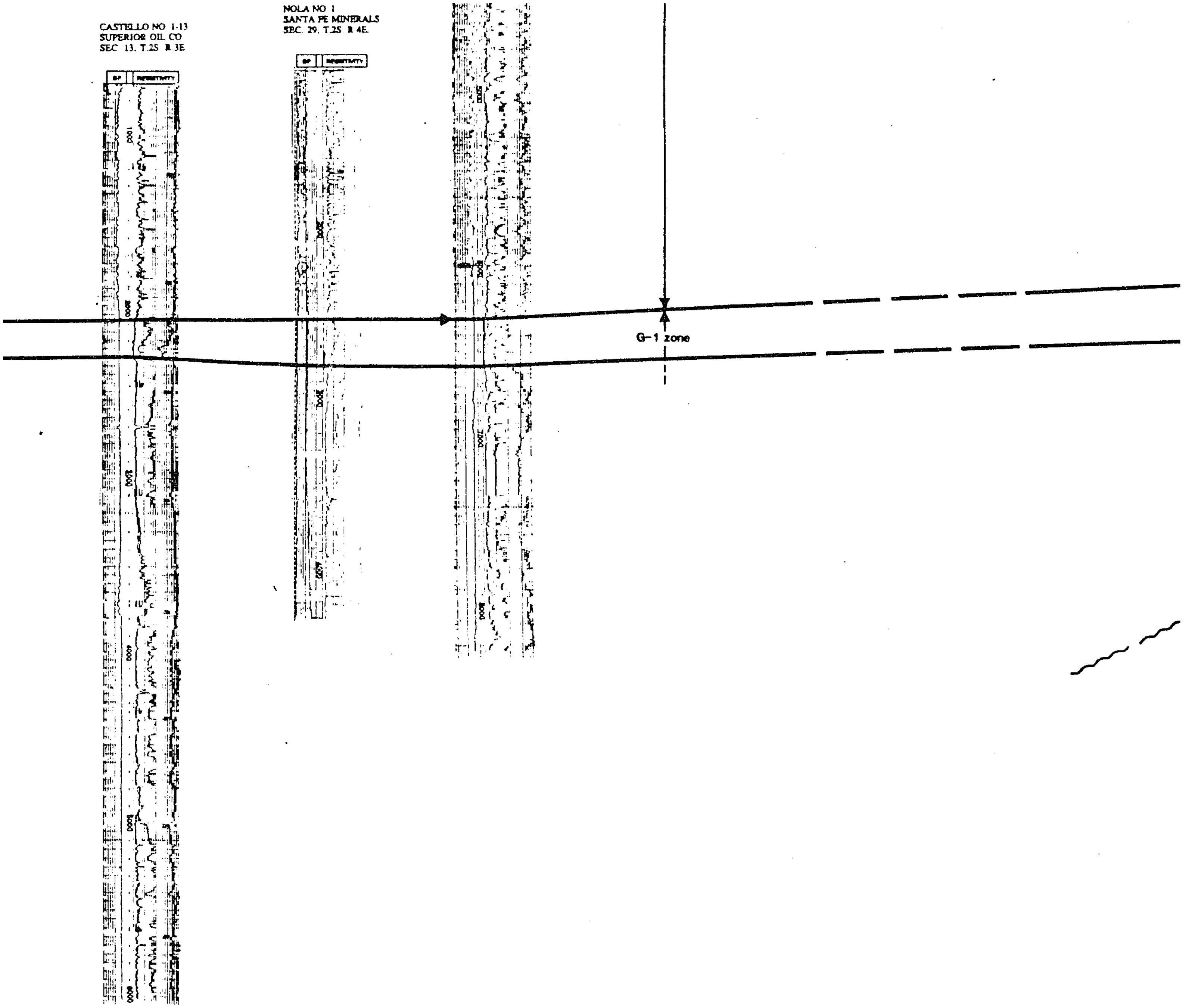
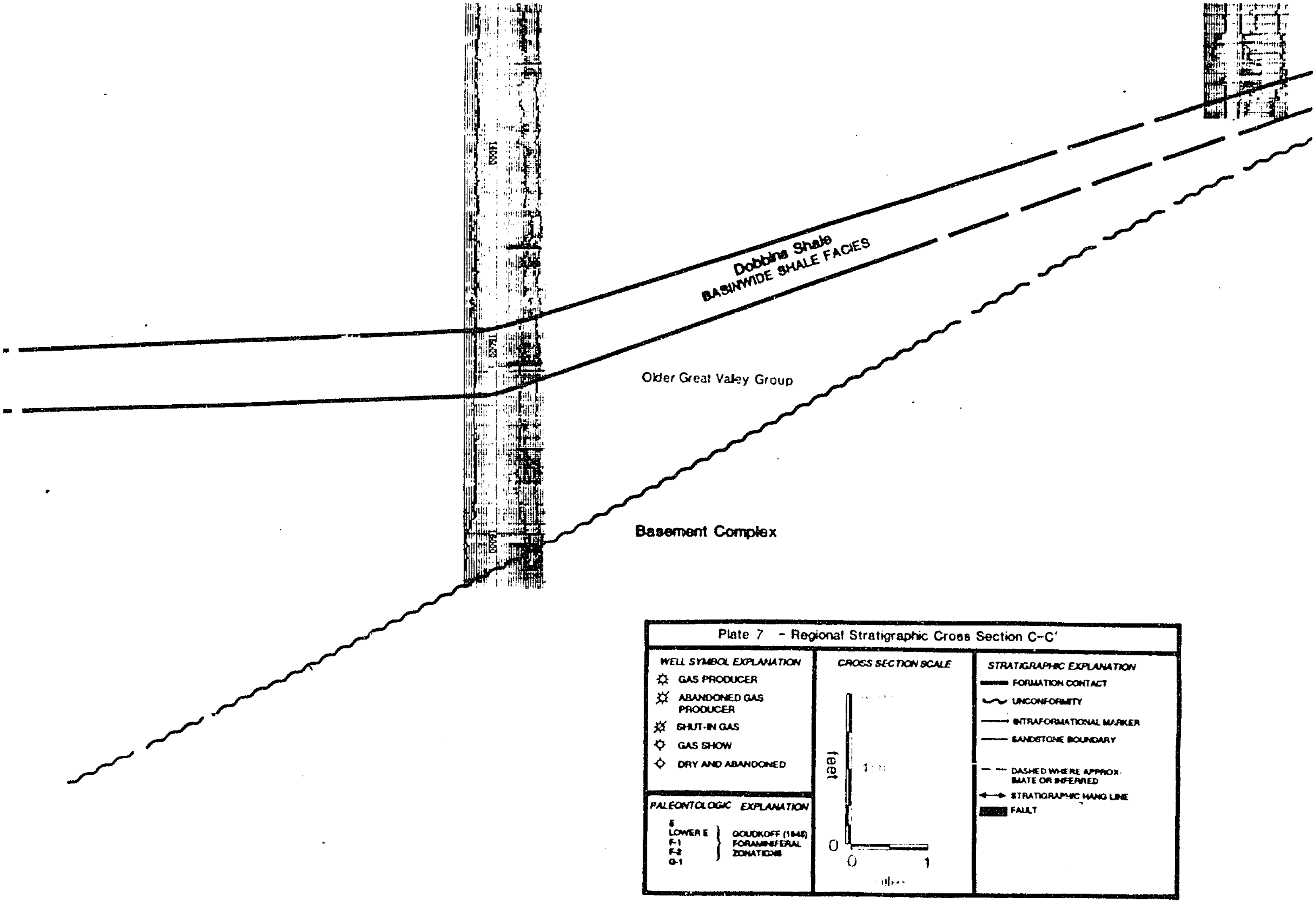


Plate 7 - Regional Stratigraphic Cross Section C-C


C'
EAST
TIES WITH E - E'
MACHADO NO 1
BERRY PET. CO
SEC. 34 T.1S R.7E
COOKSON NO 1
NARECO CORP
SEC. 29 T.1S R.8E
TIES WITH D - D'
I.H. HAYES NO 24-1A
AMOCO PROD. CO
SEC. 24 T.2S R.6E
SP
RESISTIVITY
Upper Campanian and
Maestrichtian Strata
Sacramento Shale
BASINWIDE SHALE FACIES
Marsh Creek Formation
SUBMARINE FAN FACIES
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Complex


DAVIDOR & DAVIDOR
SEC 19, T.1S R.3E
CASTELLO NO 1
SUPERIOR OIL C
SEC 13, T.2S R.
SP
RESISTIVITY
2000
1000
0
DATUM
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group


CASTELLO NO 1-13
SUPERIOR OIL CO
SEC 13, T.2S R.3E
NOLA NO 1
SANTA FE MINERALS
SEC. 29, T.2S R 4E
SP
RESISTIVITY
G-1 zone


Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Complex
Plate 7 - Regional Stratigraphic Cross Section C-C'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
feet
0
0
1
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT

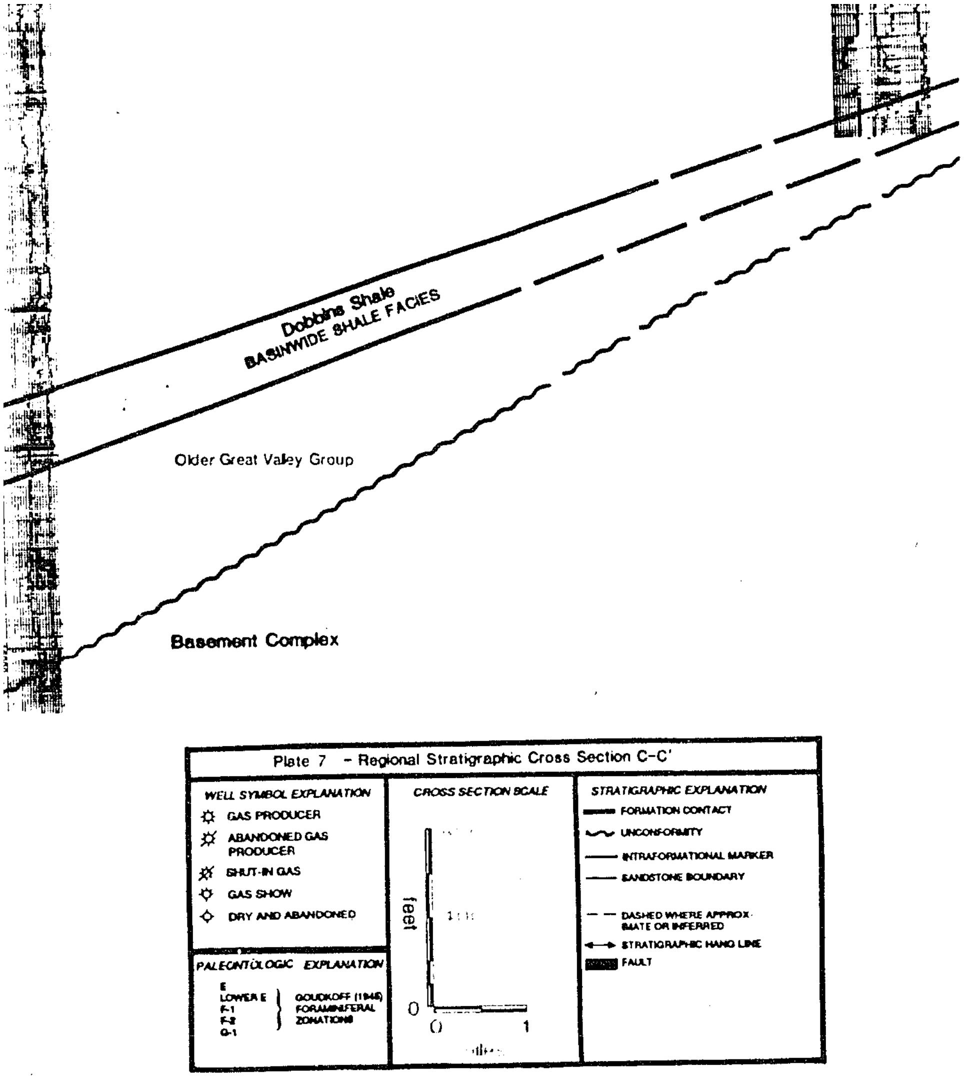


Plate 7 - Regional Stratigraphic Cross Section C-C'

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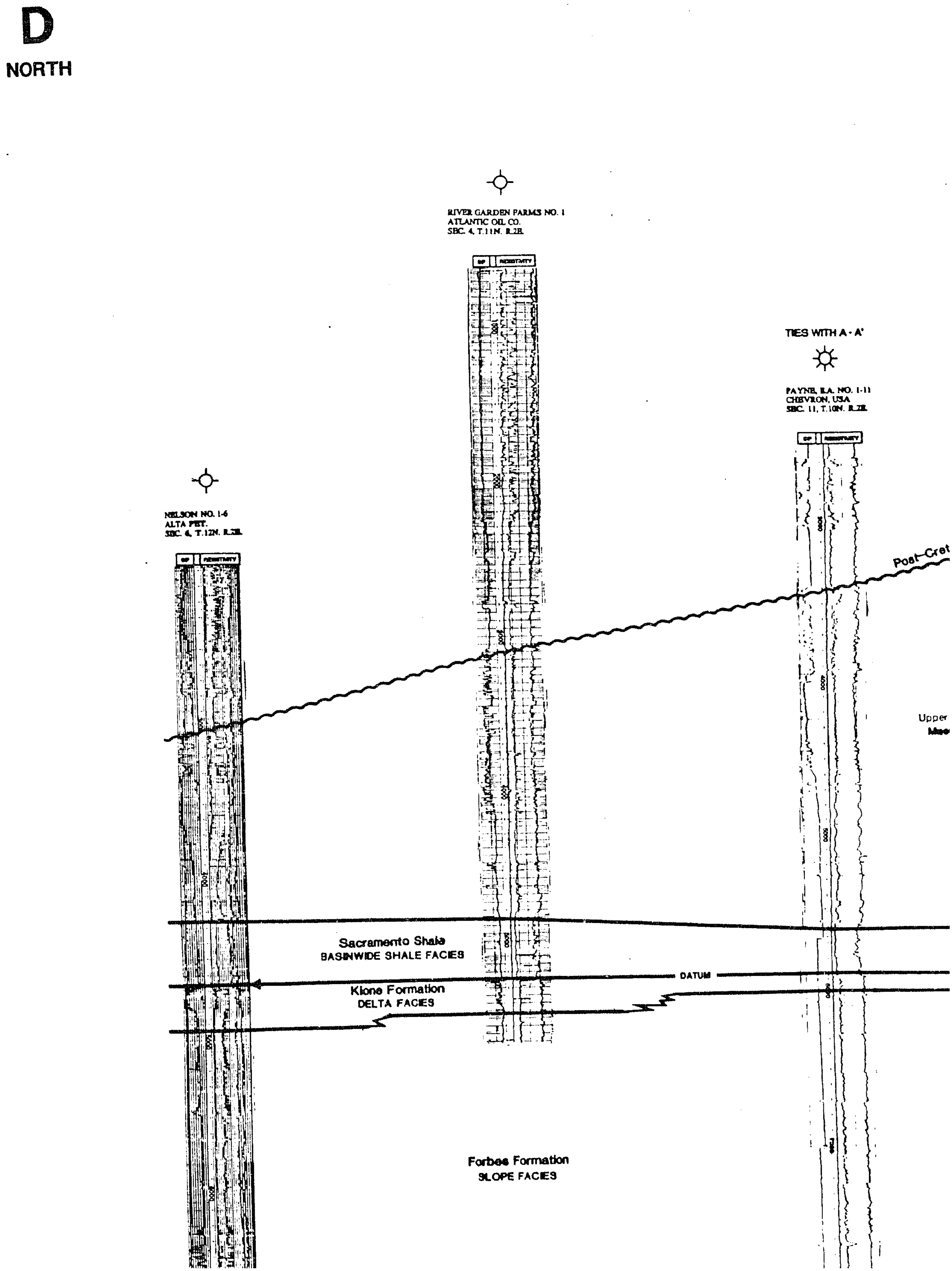
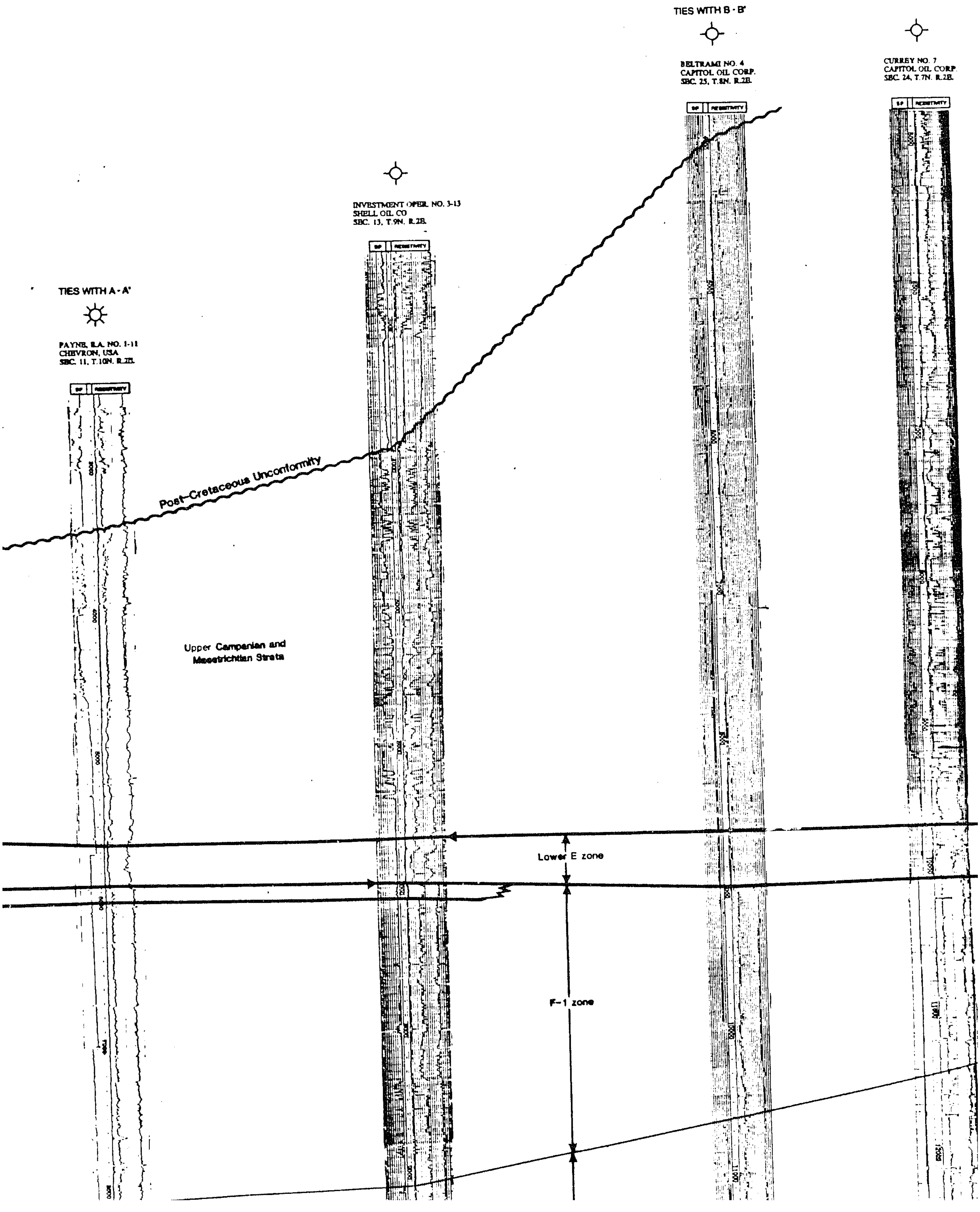
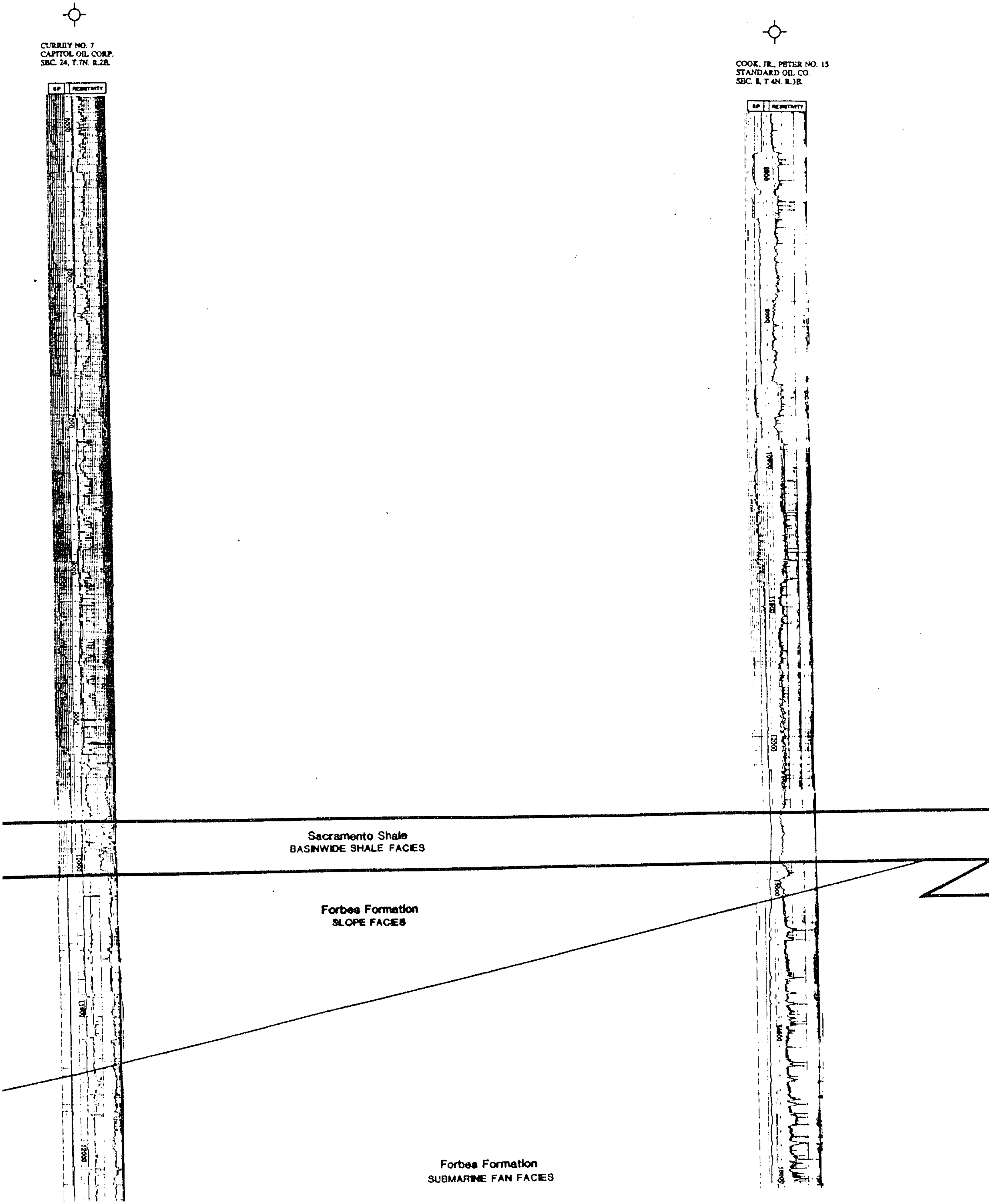
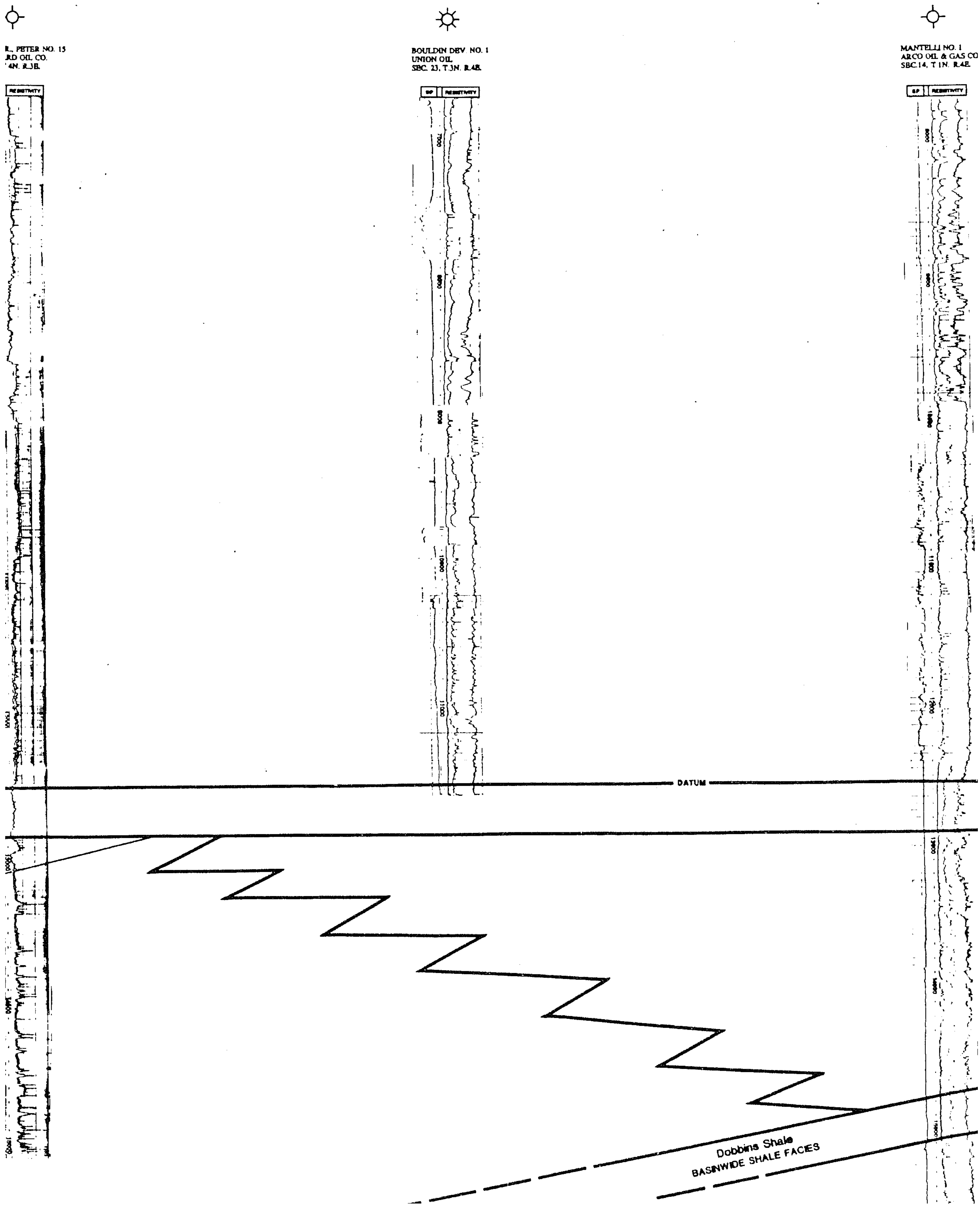
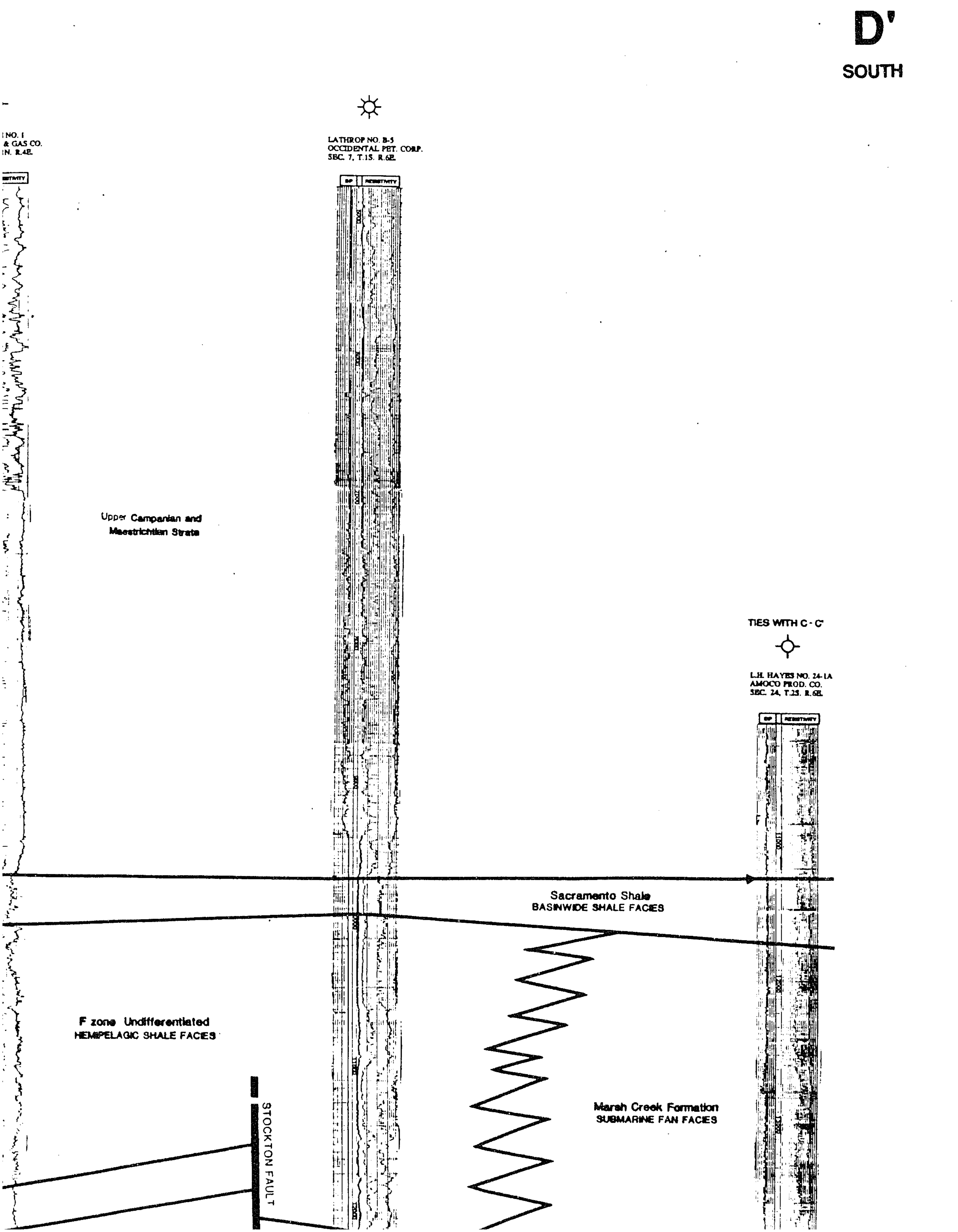

D
NORTH
RIVER GARDEN PARMS NO. 1
ATLANTIC OIL CO.
SEC. 4, T.11N. R.2E.
TIES WITH A - A'
PAYNE, R.A. NO. 1-11
CHEVRON, USA
SEC. 11, T.10N. R.2E.
NELSON NO. 1-6
ALTA PET.
SEC. 6, T.12N. R.2E.
SP
RESISTIVITY
Post-Cret
Upper
Sacramento Shale
BASINWIDE SHALE FACIES
DATUM
Klone Formation
DELTA FACIES
Forbes Formation
SLOPE FACIES


TIES WITH B - B'
BELTRAMI NO. 4
CAPITOL OIL CORP.
SEC. 25, T.8N. R.2E.
CURREY NO. 7
CAPITOL OIL CORP
SEC. 24, T.7N. R.2E.
INVESTMENT OPER. NO. 3-13
SHELL OIL CO
SEC. 13, T.9N. R.2E.
TIES WITH A - A'
PAYNE, E.A. NO. 1-11
CHEVRON, USA
SEC. 11, T.10N. R.2E.
SP
RESISTIVITY
Post-Cretaceous Unconformity
Upper Campanian and
Maestrichtian Strata
Lower E zone
F-1 zone

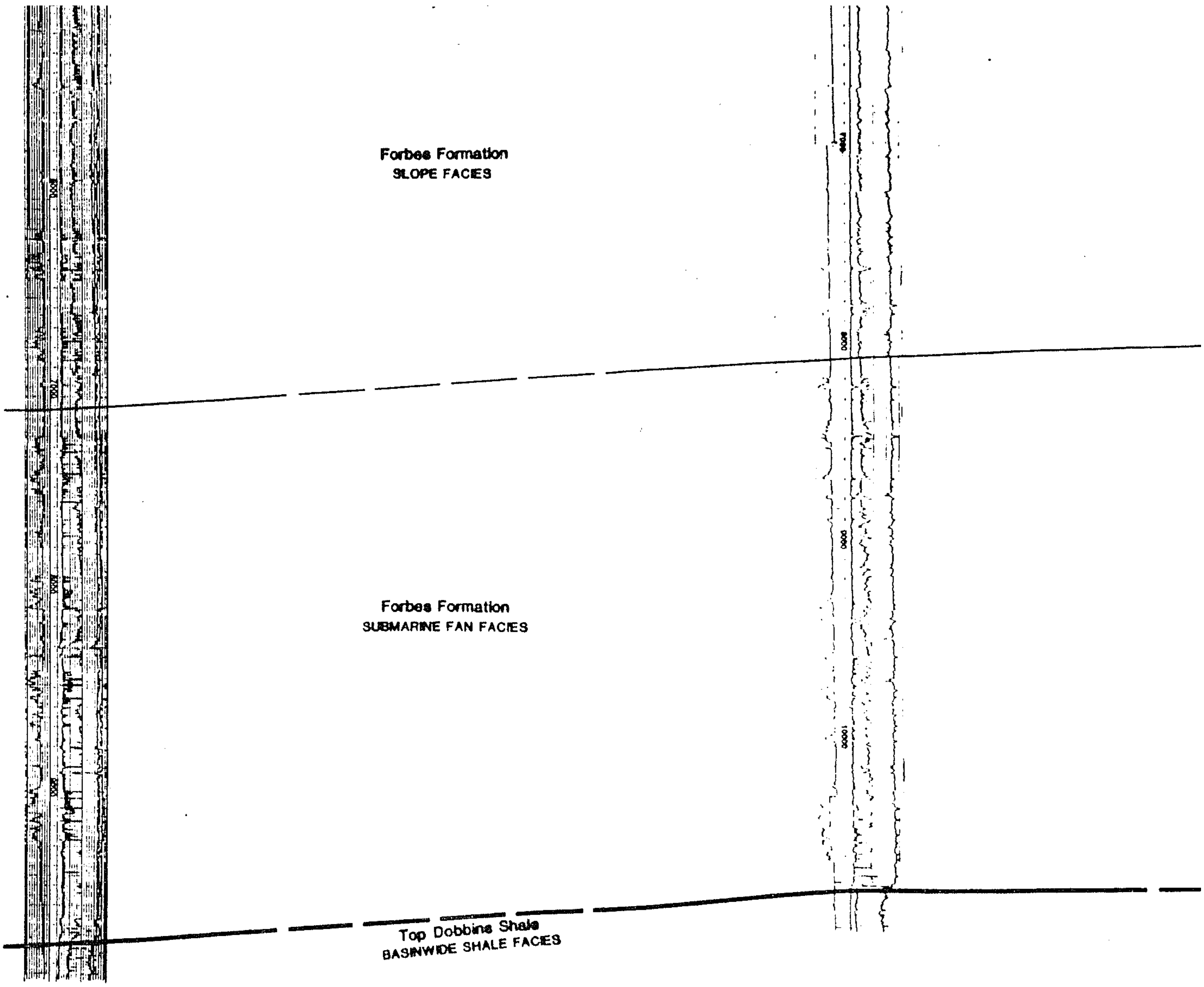

CURREY NO. 7
CAPITOL OIL CORP.
SEC. 24, T.7N. R.2E.
SP
RESISTIVITY
COOK, JR., PETER NO. 15
STANDARD OIL CO.
SEC. 8, T 4N. R.3E.
SP
RESISTIVITY
Sacramento Shale
BASINWIDE SHALE FACIES
Forbes Formation
SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES

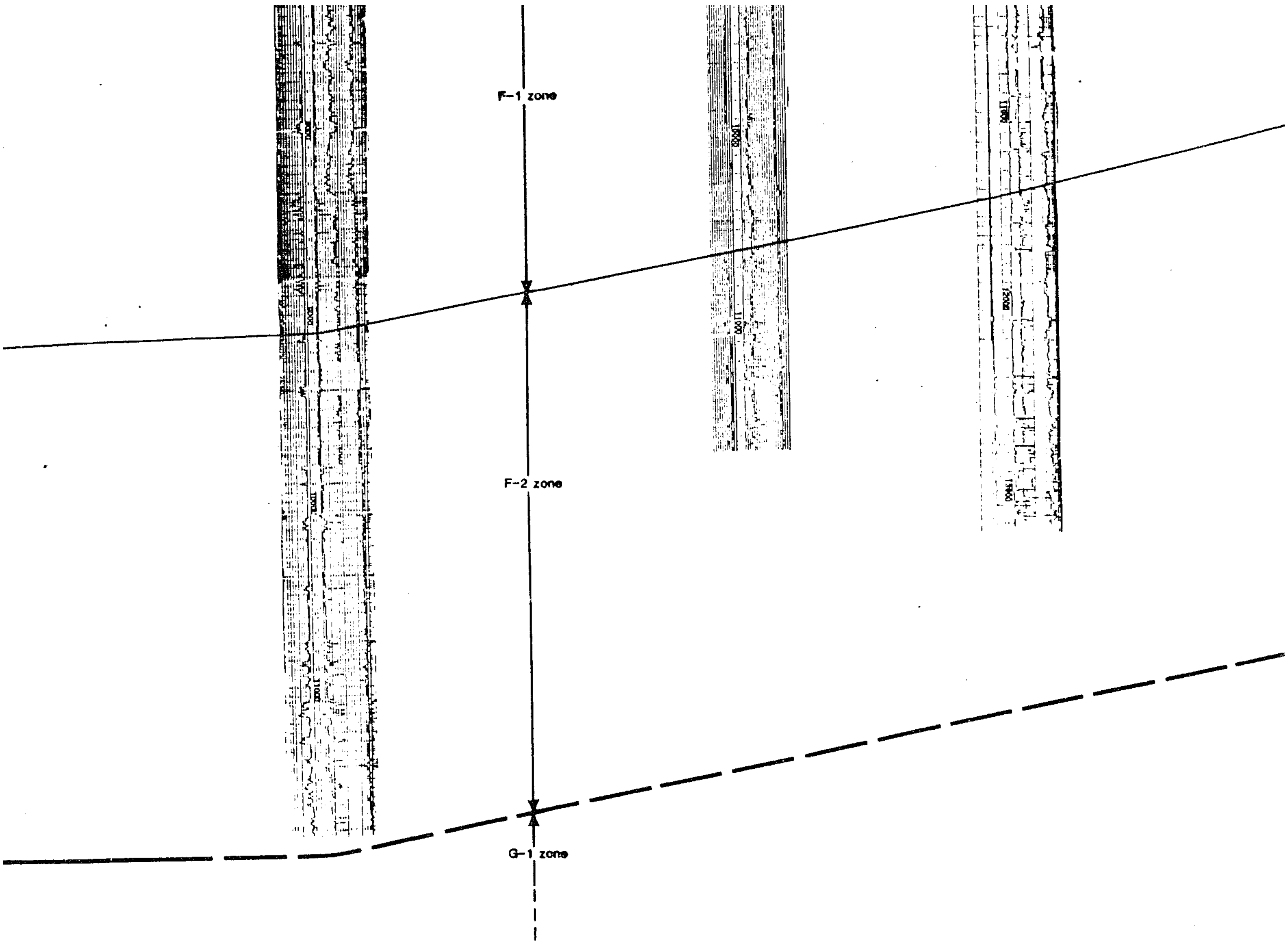


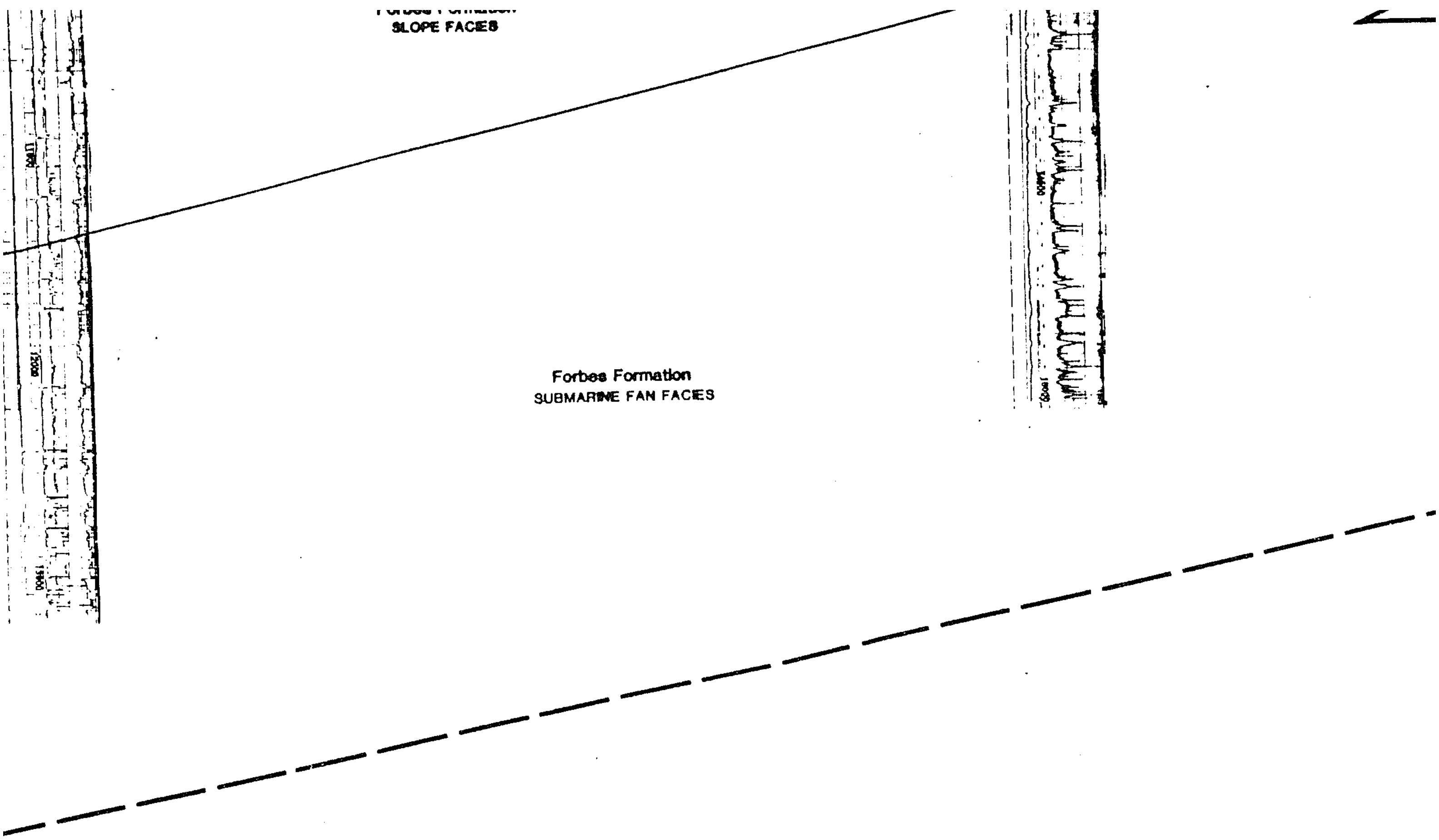
R. PETER NO. 15
RD OIL CO.
4N. R.3E.
RESISTIVITY
BOULDIN DEV NO. 1
UNION OIL
SEC. 23, T.3N. R.4E.
SP
RESISTIVITY
MANTELLI NO. 1
ARCO OIL & GAS CO
SEC.14, T.1N. R.4E.
SP
RESISTIVITY
DATUM
Dobbins Shale
BASINWIDE SHALE FACIES

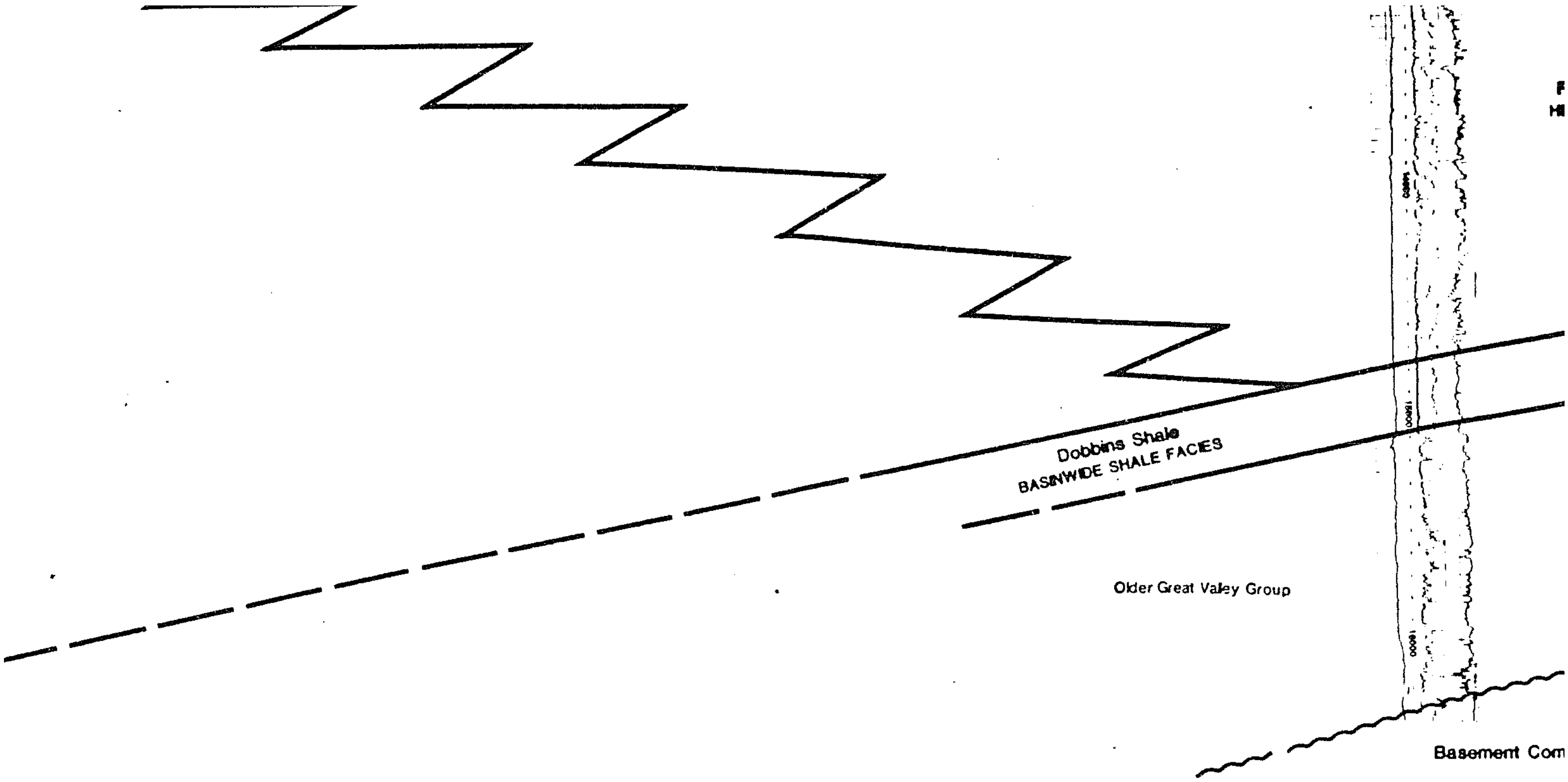


D'
SOUTH
NO. 1
& GAS CO.
N. R.4E.
RESISTIVITY
LATHROP NO. B-5
OCCIDENTAL PET. CORP.
SEC. 7, T.1S. R.6E.
SP
RESISTIVITY
Upper Campanian and
Maestrichtian Strata
TIES WITH C - C'
L.H. HAYES NO. 24-1A
AMOCO PROD. CO.
SEC. 24, T.2S. R.6E.
SP
RESISTIVITY
11000
Sacramento Shale
BASINWIDE SHALE FACIES
F zone Undifferentiated
HEMIPELAGIC SHALE FACIES
STOCKTON FAULT
Marsh Creek Formation
SUBMARINE FAN FACIES


Forbes Formation
SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES
Top Dobbins Shale
BASINWIDE SHALE FACIES


F-1 zone
F-2 zone
G-1 zone


SLOPE FACIES
Forbes Formation
SUBMARINE FAN FACIES



Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Com

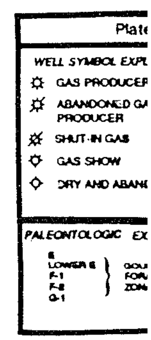
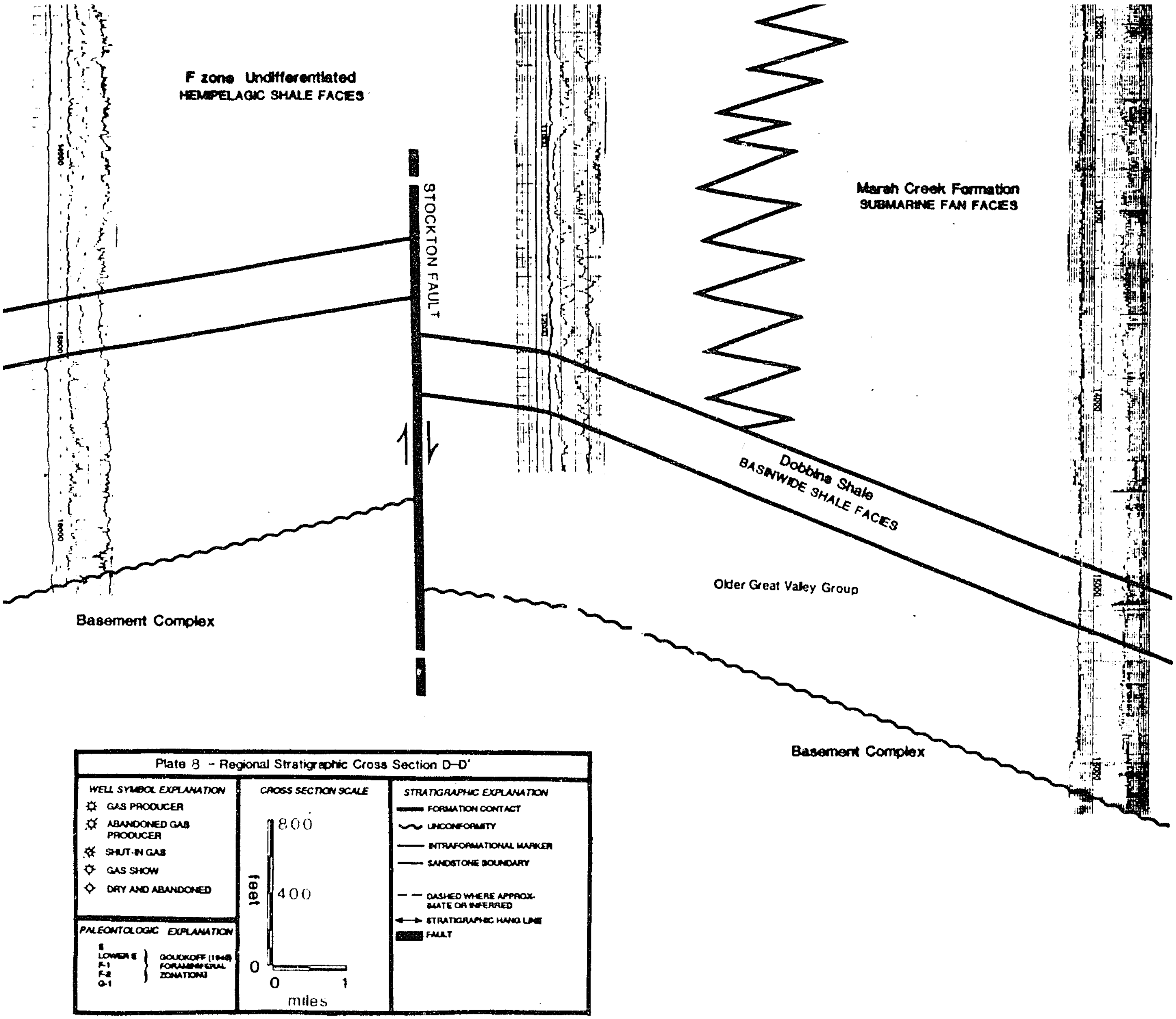


Plate
WELL SYMBOL EXPL
GAS PRODUCER
ABANDONED GA PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABAN
PALEONTOLOGIC EX
E
LOWER E
F-1
F-2
G-1


F zone Undifferentiated
HEMIPELAGIC SHALE FACIES
STOCKTON FAULT
Marsh Creek Formation
SUBMARINE FAN FACIES
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Complex
Basement Complex
Plate 8 - Regional Stratigraphic Cross Section D–D'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT

PLEASE NOTE:

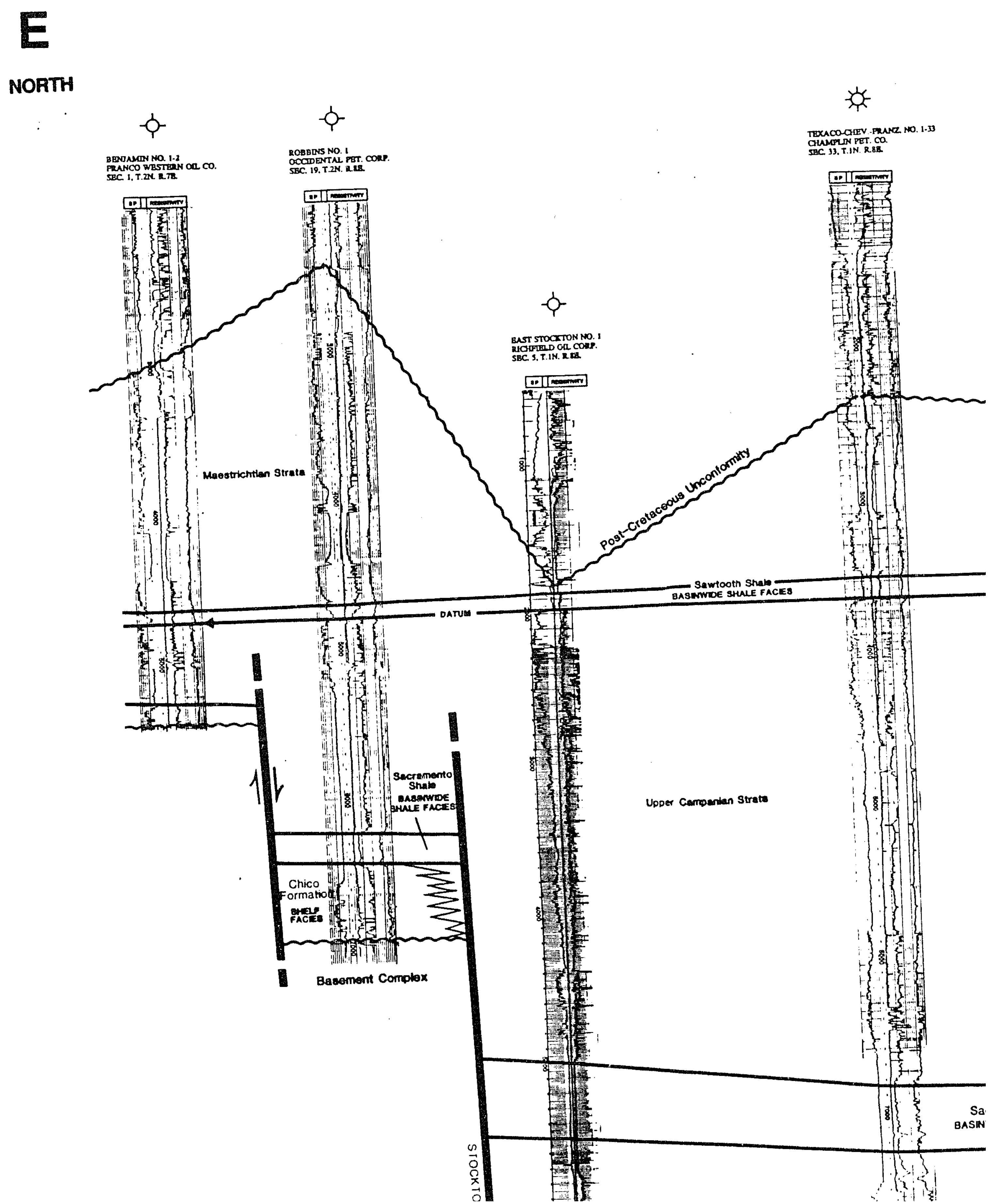
Oversize maps and charts are filmed in sections in the following manner:

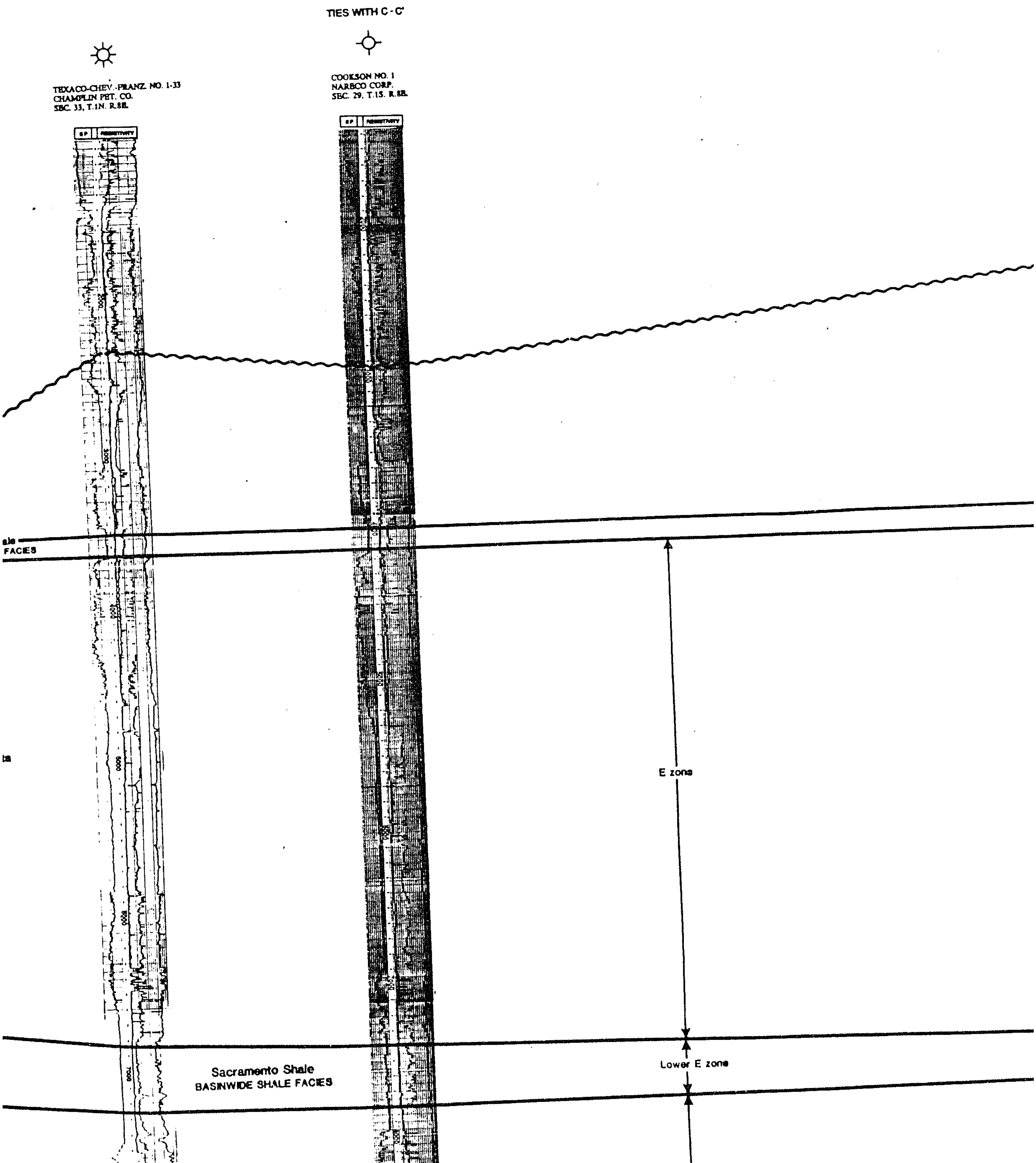
LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Black and white photographic prints (17" x 23") are available for an additional charge.

University Microfilms International


E
NORTH
BENJAMIN NO. 1-2
FRANCO WESTERN OIL CO.
SEC. 1, T.2N. R.7E.
ROBBINS NO. 1
OCCIDENTAL PET. CORP.
SEC. 19, T.2N. R.8E.
EAST STOCKTON NO. 1
RICHFIELD OIL CORP.
SEC. 5, T.1N. R.8E.
TEXACO-CHEV.-FRANZ NO. 1-33
CHAMPLIN PET. CO.
SEC. 33, T.1N. R.8E.
SP
RESISTIVITY
Maestrichtian Strata
Post-Cretaceous Unconformity
Sawtooth Shale
BASINWIDE SHALE FACIES
DATUM
Sacramento Shale
BASINWIDE SHALE FACIES
Chico Formation
SHELF FACIES
Basement Complex
Upper Campanian Strata



TIES WITH C - C'
TEXACO-CHEV.-FRANZ. NO. 1-33
CHAMPLIN PET. CO.
SEC. 33, T.1N. R.8E.
COOKSON NO. 1
NARBCO CORP.
SEC. 29, T.1S. R.8E.
SP
RESISTIVITY
FACIES
E zone
Lower E zone
Sacramento Shale
BASINWIDE SHALE FACIES

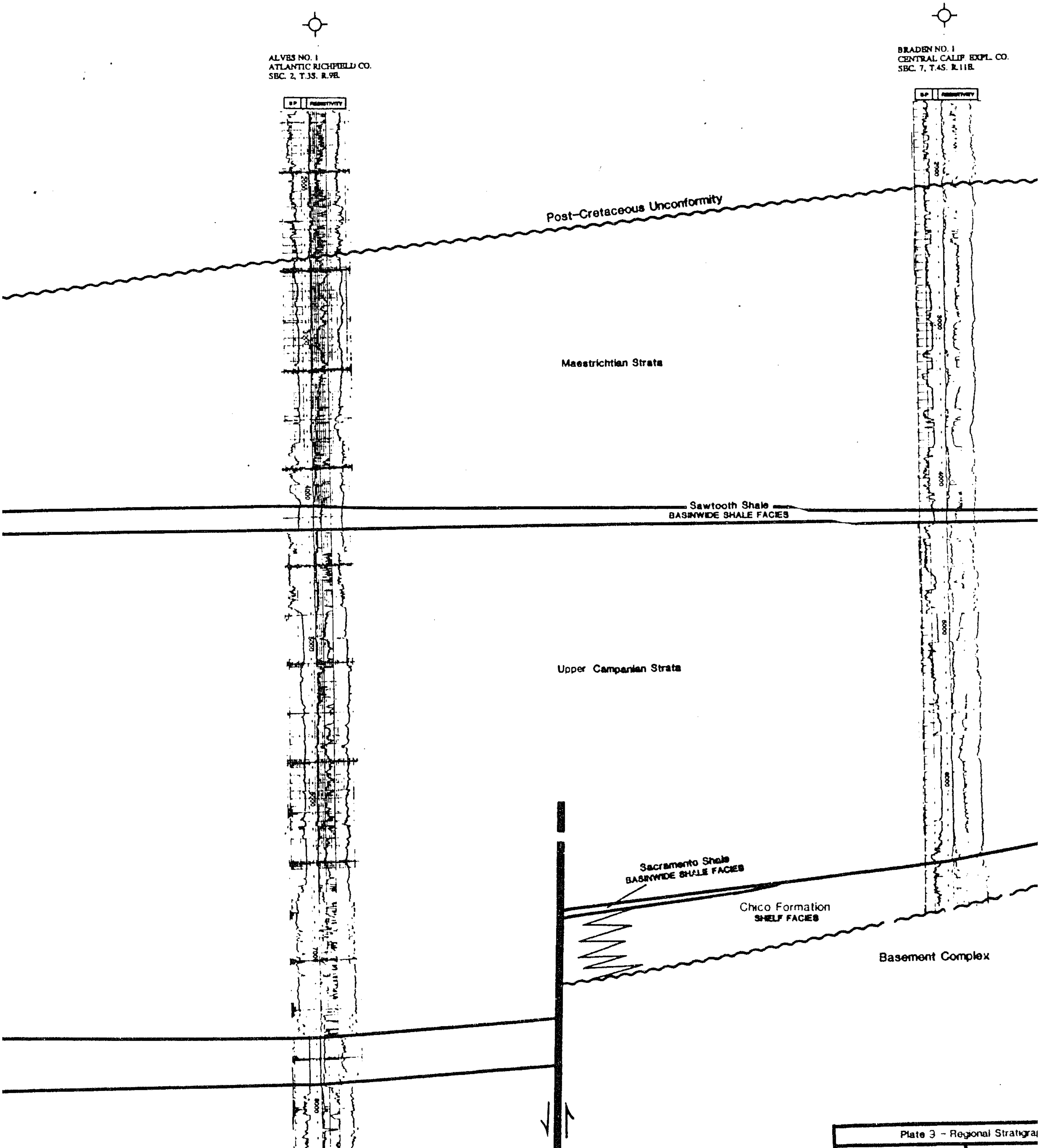
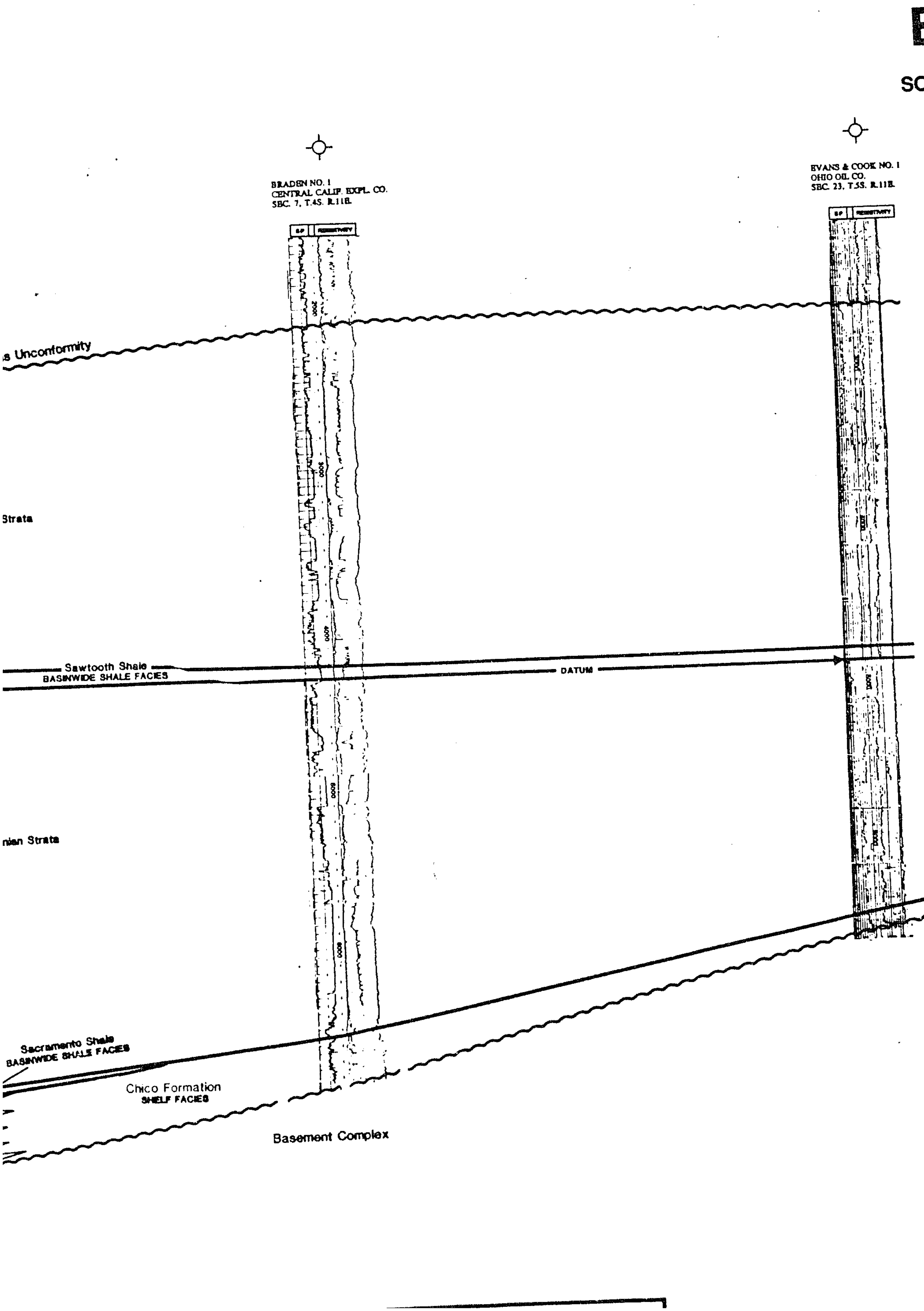
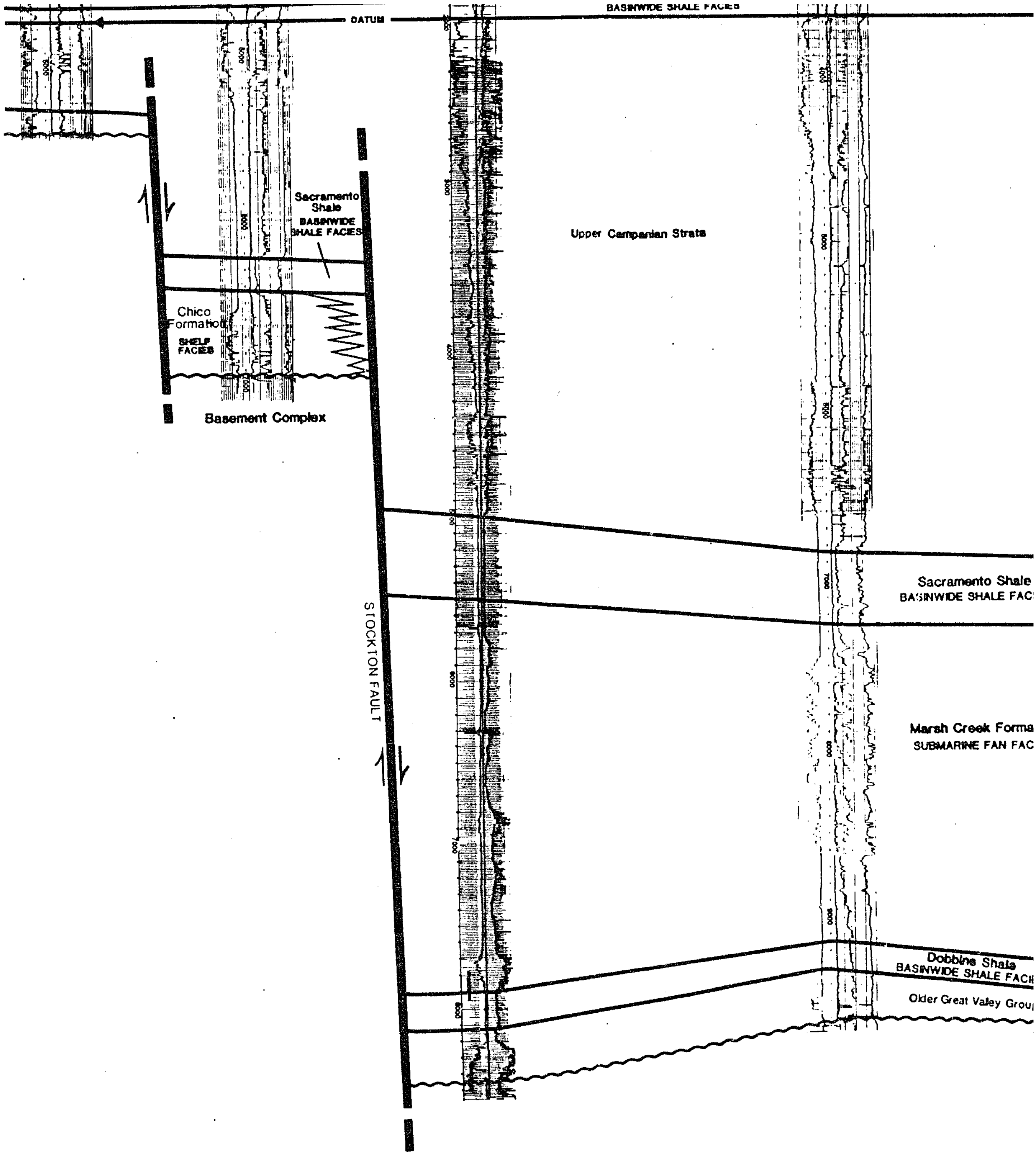


Plate 3 - Regional Stratigra

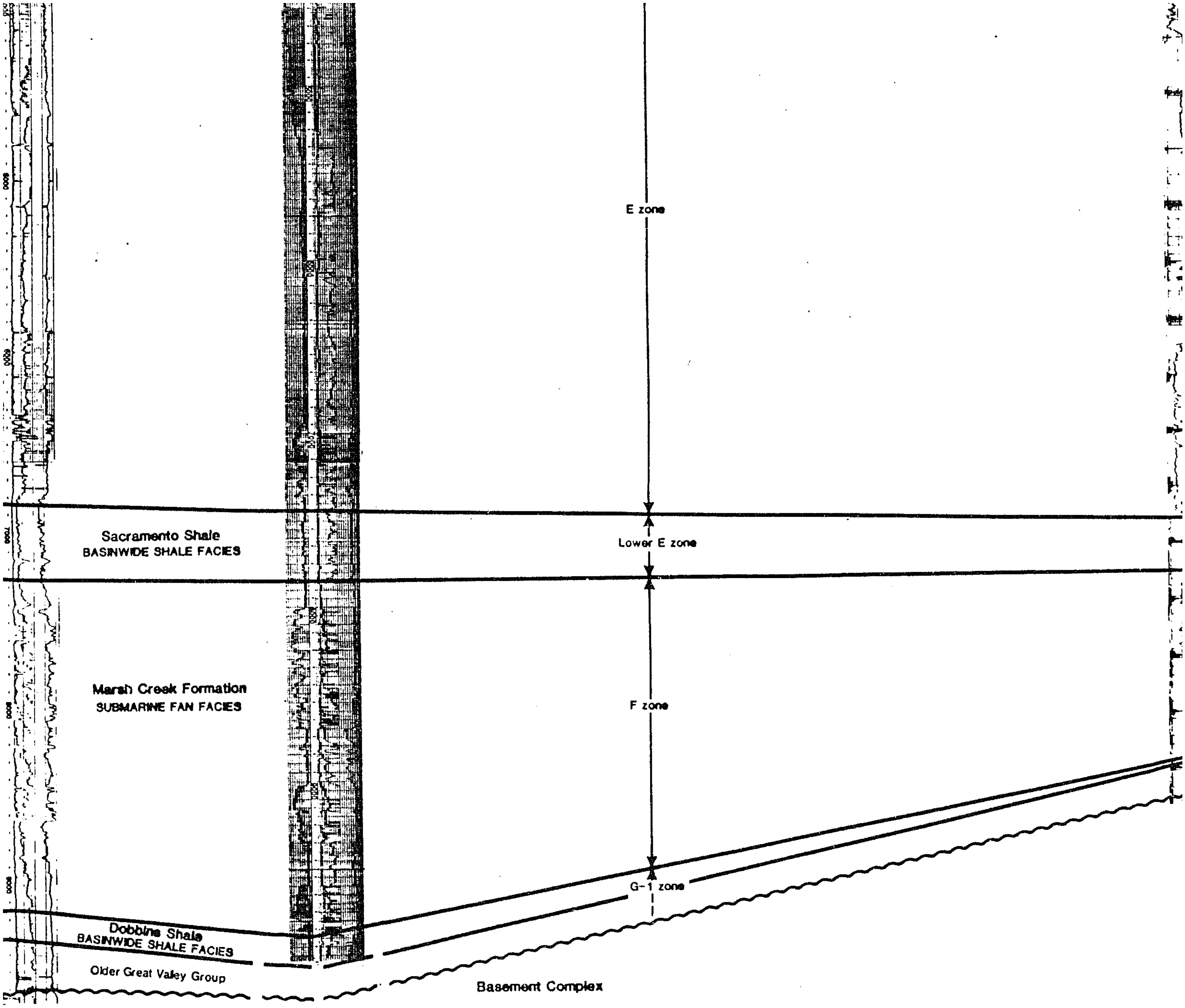
WELL SYMBOL EXPLANATION

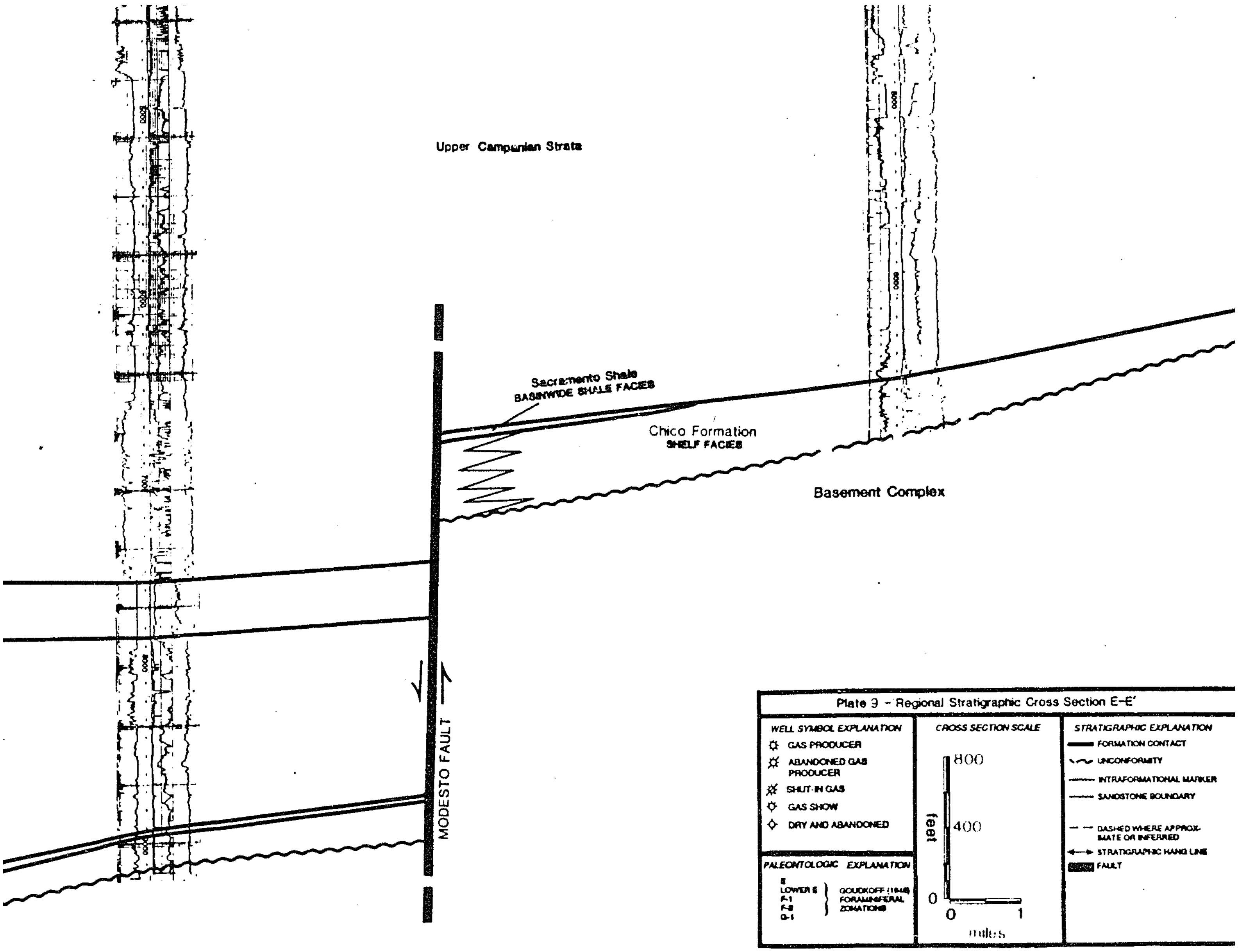
CROSS SECTIO


E'
SOUTH
BRADEN NO. 1
CENTRAL CALIF. EXPL. CO.
SEC. 7, T.4S. R.11E.
EVANS & COOK NO. 1
OHIO OIL CO.
SEC. 23, T.5S. R.11E.
s Unconformity
Strata
Sawtooth Shale
BASINWIDE SHALE FACIES
DATUM
nian Strata
Sacramento Shale
BASINWIDE SHALE FACIES
Chico Formation
SHELF FACIES
Basement Complex

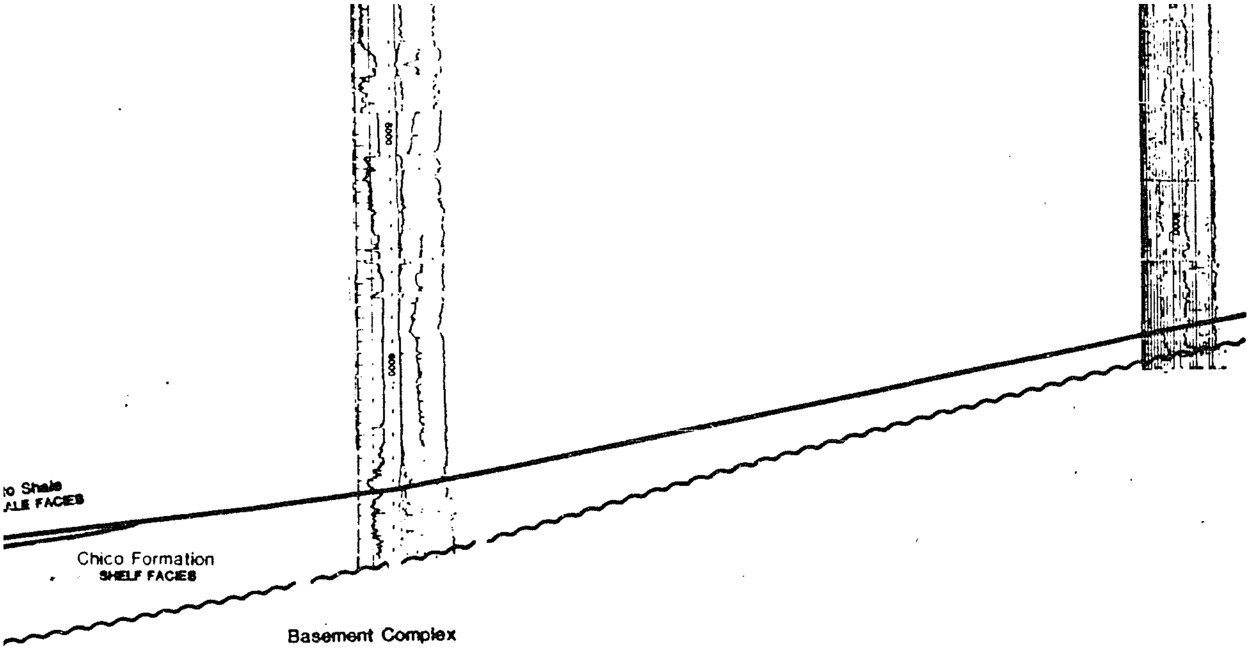


BASINWIDE SHALE FACIES
DATUM
Sacramento Shale
BASINWIDE SHALE FACIES
Chico Formation
SHELF FACIES
Basement Complex
Upper Campanian Strata
STOCKTON FAULT
Sacramento Shale
BASINWIDE SHALE FAC
Marsh Creek Forma
SUBMARINE FAN FAC
Dobbins Shale
BASINWIDE SHALE FACI
Older Great Valley Grou


E zone
Sacramento Shale
BASINWIDE SHALE FACIES
Lower E zone
Marsh Creek Formation
SUBMARINE FAN FACIES
F zone
G-1 zone
Dobbins Shale
BASINWIDE SHALE FACIES
Older Great Valley Group
Basement Complex



Upper Campanian Strata
Sacramento Shale
BASINWIDE SHALE FACIES
Chico Formation
SHELF FACIES
Basement Complex
MODESTO FAULT
Plate 9 - Regional Stratigraphic Cross Section E-E'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT



o Shale
ALE FACIES
Chico Formation
SHELF FACIES
Basement Complex

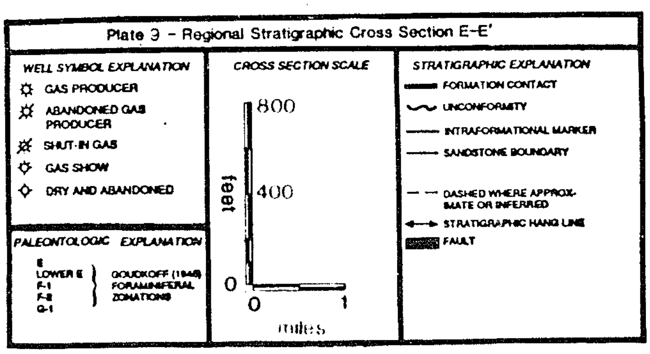


Plate 9 - Regional Stratigraphic Cross Section E-E'
WELL SYMBOL EXPLANATION
GAS PRODUCER
ABANDONED GAS PRODUCER
SHUT-IN GAS
GAS SHOW
DRY AND ABANDONED
PALEONTOLOGIC EXPLANATION
E
LOWER E
F-1
F-2
G-1
GOUDKOFF (1945) FORAMINIFERAL ZONATIONS
CROSS SECTION SCALE
800
400
0
feet
0
1
miles
STRATIGRAPHIC EXPLANATION
FORMATION CONTACT
UNCONFORMITY
INTRAFORMATIONAL MARKER
SANDSTONE BOUNDARY
DASHED WHERE APPROXIMATE OR INFERRED
STRATIGRAPHIC HANG LINE
FAULT